ORDER

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GENERAL COMMUNICATIONS HANDBOOK

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DEPARTMENT OF TRANSPORTATION
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RECORD OF CHANGES

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CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE	CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE

FOREWORD

This order presents information of a technical nature that relates to siting criteria, operational reliability and availability considerations, technical factors affecting air-to-ground (a-g) communications associated with terminal and en route communications, and recommendations for standardization of future communications configurations.

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CHAPTER 1. GENERAL INFORMATION

1. PURPOSE. This order is to be used as a supplement to two associated orders, Order , Terminal Communications Installation Standards Handbook, and Order , En Route Communications Installation Standards Handbook.

2. DISTRIBUTION. This order is distributed to branch level in the Program Engineering and Maintenance and Systems Engineering Services in Washington headquarters; to branch level in the regional Airway Facilities divisions; to branch level in the Airway Engineering Support Division and FAA Academy at the Aeronautical Center; to branch level in the Engineering Management Staff and the Aviation Facilities and Data Engineering and Development Divisions at the FAA Technical Center; and limited distribution to all Airway Facilities sectors.

3. SCOPE. This order covers topics of a technical nature relating to siting criteria, reliability and availability considerations, and technical factors affecting air-to-ground (a-g) communications associated with terminal and en route facilities.

4. SAFETY. Personnel shall be cautious at all times while working on equipment, particularly where dangerously high voltages are employed, and especially when inspection plates and dust covers are removed or access doors are opened exposing internal wiring. Contact with alternating current (ac), direct current (dc), or radio frequency (rf) potentials can result in severe shock, burns, or loss of life. Maintenance personnel should familiarize themselves with the technique for resuscitation found in the manual of first aid instructions. All individuals are expected to be thoroughly familiar with general safety practices prior to working on equipment so as not to endanger themselves or others. In particular, operating and maintenance personnel are directed to the latest editions of FAA Order 6000.15, General Maintenance Handbook of Airway Facilities, and the 3900 Series for safety precautions to be observed. Ignorance and carelessness are the predominant factors involved in most accidents. PARTICULAR ATTENTION SHALL BE GIVEN TO THE PROPER USE OF THE GROUNDING CABLE PRIOR TO WORKING ON HIGH-VOLTAGE CIRCUITS. NOTE THAT UNDER CERTAIN CONDITIONS, DANGEROUS POTENTIALS MAY EXIST IN CIRCUITS WITH POWER CONTROLS IN THE OFF POSITION BECAUSE OF CHARGES RETAINED BY CAPACITORS. TO AVOID CASUALTIES, ALWAYS REMOVE POWER, THEN DISCHARGE AND GROUND BY USE OF A GROUNDING ROD PRIOR TO TOUCHING ANY PARTS.

5. WAIVERS. Refer to the latest edition of Order 6000.20, Waiver of Criteria for Establishment and Maintenance of Airway Facilities, for current policy and instructions concerning inability to meet prescribed standards, and/or operating or continuing to operate nonstandard facilities.

6.-8. RESERVED.

CHAPTER 2. SITING CRITERIA

9. GENERAL. This section reviews the actions which must be considered by FAA field engineers, planners, and implementation personnel when selecting a proposed location for a new airport traffic control tower (ATCT), a remote transmitter site, a remote receiver site, a combined remote transmitter-receiver (RTR) site, or a remote center air-to-ground (RCAG) site.

10. SYSTEM CONFIGURATION.

a. To provide required area coverages and to minimize transmitter intermodulation (im) interference and receiver desensitization effects, transmitter and/or receiver equipment associated with terminal and en route a-g communications may have to be remotely located from the ATCT or air route traffic control center (ARTCC). In general, the three categories of airport control towers are nonapproach, nonradar approach, and radar approach. Each category utilizes a particular configuration for a remote facility, if one is required, as does the ARTCC. At radar approach control towers where the activity level is quite high, as many as three remote sites may be required to prevent interference effects. The minimum distance required between remote sites to minimize im interference effects is 1,500 feet; the minimum distance between transmit and receive antennas to prevent receiver desensitization is 80 feet. Remote sites associated with control towers are usually located at or near the airport they serve and are linked to the ATCT by means of voice frequency (vf) cables or very high frequency (vhf) terminal links. While the above guidelines represent optimum conditions, economical considerations must not be ignored. In an effort to reduce costs, the National Airspace System Plan (NASP) calls for future consolidation of sites. For a more detailed discussion on goals to be achieved, refer to the NASP.

b. An RCAG, which is similar to an RTR (transmitters and receivers are collocated), is usually located many miles from its controlling centers and is linked to the ARTCC by leased Telco lines or radar microwave link. Both technical and economic factors must be considered when determining suitable locations for these different remote sites.

11. SITE SURVEY. After the performance and operational parameters of a candidate ATCT or remote site have been defined, the problem of geographically locating these sites must be determined. Preliminary studies can usually be made from maps, but a final site selection must be made from more detailed information gathered from a field survey.

a. Maps. Accurate topographic maps are available for many areas of the United States from the U.S. Geological Survey offices. These maps provide detailed terrain information essential to any radio site selection process. Aeronautical charts and airport site plans are also useful as a source of information. County highway maps, available in many areas, seldom give any detailed elevation information but are useful in planning survey trips and for site accessibility studies. These maps are usually up to date and contain detailed information on roads, buildings, bridges, and other structures. The maps should be analyzed and searched for locations from which complete, unobstructed coverage appears possible.

b. Field Survey. The purpose of the field survey is to visit the potential sites and to verify the preliminary data. Often, the clearance of the radio paths can be verified by visual sighting with a pair of field glasses. Assuming a 75-foot tower height, the antenna must be high enough or located in such a manner as to provide an unobstructed propagation path down to an elevation angle of 2 degrees above the horizontal plane of the antenna. Future vegetation growth must be considered. This angle can easily be measured with a transit, only if the transit is at the same elevation as the proposed antenna. Otherwise, it must be estimated based on the measured angle (estimated or scaled on a map) to the obstruction. (Acceptability of 2 degrees shielding may vary with coverage requirements. This shielding shadow will be approximately 6,000 feet above the site at 30 nautical miles.) In the case of remote transmitter, remote receiver, and remote transmitter-receiver sites, a clean line-of-sight (los) path must also exist between the antenna and all taxiways, ramps, and runways. If unobstructive line-of-sight paths cannot be met due to surrounding structures, verification of required coverage by radio check is acceptable. During these field surveys, a considerable amount of information should be gathered about each proposed site. This information is necessary to properly evaluate the relative merits of each site and to plan for site development when a final choice has been made. As a minimum, the following information must be gathered:

(1) Location. By latitude and longitude, word description, and access route. For terminal facilities, site location should be given relative to an airport master plan.

(2) Accessibility. Type and length of access road required; distance from nearest highway and condition of existing roads.

(3) Power. Determine availability, adequacy, and reliability of ac power.

(4) Airports. Distance and direction to nearest airport for construction permits and runway clearance planes (transition slopes).

(5) Area. Amount of land available for building and tower construction.

(6) Right-of-Way. Availability of land and right-of-way.

(7) Clearing. Amount of clearing required before the site can be developed.

(8) Soil. Type of soil on which the building and towers will be built; a soil conductivity test should be performed to determine grounding requirements.

(9) Existing Structures. Description of any existing FAA building or towers that may be used for the new station.

(10) Obstructions. Types of local obstructions and tower heights required to provide local clearances.

(11) Weather. Any unusual weather conditions to be expected in the area, including amount of snow and ice accumulations and maximum expected wind velocities.

(12) Temperature. Highest and lowest temperatures to be expected so that proper heating and ventilation can be provided.

(13) Interference. Description and distance to any commercial or FAA facility that could cause interference, or be affected itself by a proposed installation. As a rule, the proposed site should be a minimum of 1,500 feet from any existing or proposed radio or radar facility and a minimum of 10,000 feet from broadcast stations with up to 500 watts of rf power. Above 500 watts, coordinate with regional Frequency Management Staff for minimum separation requirement.

(14) Traffic Patterns. Drawings should be made showing airborne traffic patterns and ground patterns, if they are significant.

(15) Economics. An economic evaluation of the site should be prepared, including estimated cost of structure, site preparation, access road, extension of facilities, etc.

(16) Environmental Impact. Depending on the location of the proposed site (Government property, industrial area, etc.), the impact of the facility on the environment must be considered. Of particular interest are the effects of the facility on local area, natural environment, and aesthetics of the surrounding area.

(17) Telco Service. Availability and adequacy to meet immediate and foreseeable requirements.

(18) Ownership of Land. Ownership, control, and availability of a potential site should be investigated as well as rights-of-way, land acquisition, right-of-entry, title, lease arrangements, letters of permission, negotiations with other Government agencies, etc.

(19) Water and Sanitation Facilities. Most communications sites do not qualify for sanitation facilities. FAA criteria for the authorization, selection, and installation of sanitary systems are contained in the latest edition of Order 6960.1, Sanitary Systems in FAA Facilities.

(20) Panoramic Photos. Panoramic photographs covering 360 degrees of azimuth may be taken from the site to study proposed sites. Appropriate elevation and azimuth markings should be added to the photographs. Panoramic photos are not generally required for establishment of a communications facility. A horizon profile taken with a transit plus photographs shot across the site in all directions are generally adequate.

(21) Horizon Profile. Horizon profile data are required to determine the radio los range in different azimuths. This information is normally provided as part of a computerized coverage plot available through the regional or Washington, D.C., frequency management office.

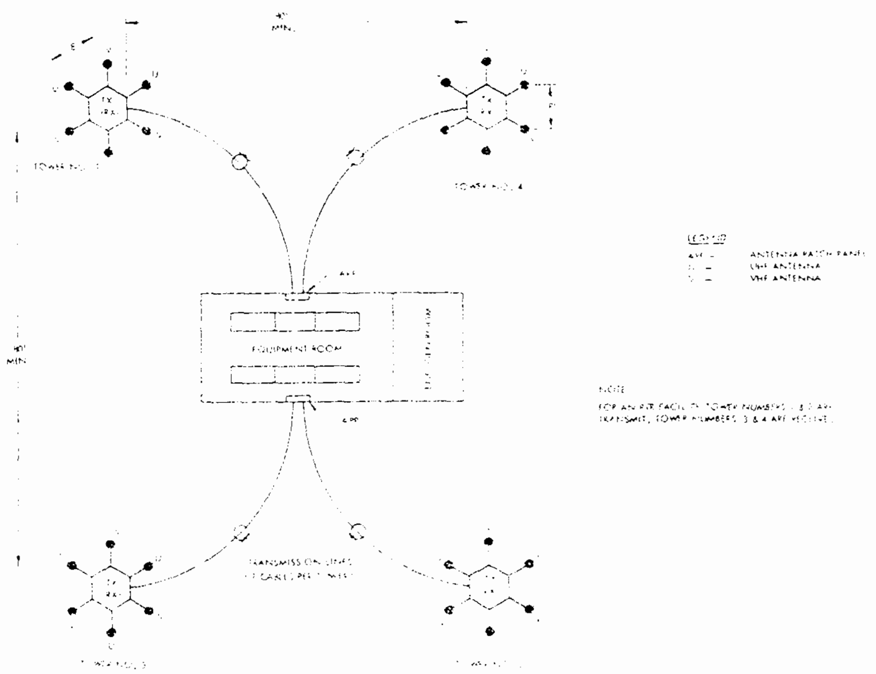
(22) Control Cables. Availability of FAA-owned control cables in the vicinity of the proposed site should be investigated.

c. Survey Data. Based on the map and field studies, the survey data should be finalized and maintained on record in the region.

12. SITE SELECTION. Technical factors involved in selecting a remote site are thoroughly covered in chapter 5. Economic factors such as proximity to main highways, availability of commercial utilities, and site preparation expenses can be determined from the survey report. Usually a trade off is involved between technical and economic factors. All pertinent factors must be weighted and evaluated for the different locations studied.

13. SITE LAYOUT. In laying out a remote site, the equipment building is usually located at the middle of the property and antenna towers are located around the building, as depicted in figure 2-1. This layout maximizes the spacing between towers and minimizes transmission line lengths. The approximate area required for a typical site is 120 by 120 feet. Standard site layouts are shown on drawing series D-6061, D-6068, D-6069, and proposed series D-6188.

FIGURE 2-1. TYPICAL REMOTE SITE LAYOUT



14. ANTENNA TOWERS. Towers currently utilized by the FAA are self-supporting or guyed steel structures that have a hexagonal platform at the top for mounting and servicing antennas.

15. ANTENNAS. Antenna criteria were based on the use and comparison of existing vhf/ultra high frequency (uhf) transmit and receive antennas and the application of a new standard antenna for both vhf and uhf frequencies. The new standard antennas employ half-wave, vertically polarized, omnidirectional dipoles enclosed in fiberglass radomes.

a. Old Standard Antennas.

Antenna analysis was based on present FAA practice of using vhf vertically polarized coaxial antennas for receive and vhf circularly polarized swastika antennas for transmit. The vertically polarized omnidirectional broadband discone antenna was used for both transmit and receive uhf frequencies. Although the swastika antenna is currently in use, its utilization will be discontinued as the new antennas become available. The old standard type of antennas does not provide the most efficient antenna pattern and, consequently, the new standard type of antennas was considered for facilities serving domestic flights. Future procurements of the old standard coaxial dipoles, swastikas, and discones are not planned.

b. New Standard Antennas.

(1) There is a significant yearly increase in communication channel requirements. In order to minimize interference and allow more efficient use of available frequency spectrum, a power reduction program was instituted in April 1975 (Order 6610.3, Power Output Limitation: FSS, Terminal and Low-Altitude En Route VHF and UHF Transmitters). This action made the use of more efficient antennas highly desirable and led to the selection of the new standard antennas. The new standard antennas come in single vhf and uhf configurations, and in uhf/uhf, vhf/vhf, and vhf/uhf configurations arranged in collinear manner. Each dipole within a stacked version is operated independently with a high degree of isolation. The antennas' electrical, mechanical, and installation characteristics are adaptable to existing and future FAA facility applications. The antennas are presently available from several sources and currently are being procured by Washington headquarters from Technical Appliance Corporation (TACO), Sherburne, N.Y., and DHV Incorporated, Mineral Wells, Texas. Currently, two gain antennas are being procured as standard antennas. A collinear, omnidirectional antenna is available for vhf use and offers approximately 4 dBi gain according to the manufacturer. A directional vhf Yagi type antenna is also available which provides 10 dBi gain. Both antennas have application when solving coverage problems.

(2) The power reduction program, mentioned above, was instituted for vhf and uhf transmitters installed in flight service stations (FSS), terminals, and low-altitude en route facilities. Ten-watt power outputs are to be used for all applications except where: (a) required coverage cannot be attained, (b) when serving a high-altitude sector, or (c) where the radius of service volume exceeds 60 nautical miles. Waiver approvals are required for higher outputs, unless serving high-altitude sectors or service volumes exceeding 60 nautical miles. Fifty-watt amplifiers are in the FAA depot stock to support coverage as required. This order is current and continues to be FAA policy regarding output power.

(3) High-altitude en route facilities are not affected by the power reduction program. Fifty-watt outputs are permissible, and indeed expected by the Air Traffic Service. However, where sectors are small and satisfactory coverage can be provided, there is no objection to the use of 10-watt power. As in the past, it is incumbent upon the Air Traffic Service to coordinate anticipated changes in sector boundaries with the Program Engineering and Maintenance Service. The importance of this coordination is magnified where 10-watt power is currently used, and 50 watts dictated by new boundaries.

16. ANTENNA SPACING AND FREQUENCY SEPARATION.

a. Maximum practical separations should be provided between antennas to minimize possible interference. The elimination of transmitter intermodulation (im) interference usually will require a greater antenna separation than that necessary to eliminate receiver im interference. In some cases, ferrite isolators may be required to reduce transmitter im interference and to permit closer spacing of transmit and receive antennas.

b. The following guidelines should be adhered to:

(1) Spacing between two remote transmitter sites, between a remote transmitter and remote receiver site, or between two remote transmitter-receiver sites shall be a minimum of 1,500 feet.

(2) Where adjacent channel frequencies, differing by 1 MHz or less, are to be collocated at the same remote site, the associated transmitting antennas shall be mounted on structures separated by at least 80 feet. Wherever possible, antennas located 80 feet from an ATCT shall be installed at an elevation as near as possible to those mounted on the roof of an ATCT, ensuring that the vision of the controller is not obstructed.

(3) Antenna support structures shall provide at least 8 feet of separation between antennas.

(4) Not more than six antennas shall be located on the same tower or in any group of antennas.

(5) Receive antennas are not normally located on the same tower or in the same group with transmit antennas. However, in special cases where only one tower is installed, it may be necessary to install transmit and receive antennas on the same tower.

(6) Where adjacent vhf or uhf frequencies differ by 1 MHz or less, the associated transmit antennas shall be mounted on separate towers or in separate groups.

(7) Roof-mounted antennas with a minimum of 8 feet separation on the abandoned Airport Surveillance Radar (ASR)-4/5/6 building are acceptable as a remote transmitter or remote receiver facility (but not RTR) if the following criteria are met:

(a) No transmitter im interference or receiver im interference is experienced.

(b) Meet air traffic coverage requirement.

(c) Space is not available to provide standard antenna tower structure.

(d) Standard antenna tower height would violate Federal Aviation Regulations, Part 77, Objects Affecting Navigation Airspace, requirements.

17. TRANSMISSION LINES.

a. Transmission lines used by the FAA are primarily coaxial cable types RG-213/U and RG-218/U. These solid-dielectric cables have some inherent deficiencies which make them inferior to foam-type cables. In future FAA installation, RG-331/U and RG-333/U (or equivalent) foam-dielectric cables should be used. The advantages of foam-dielectric cable are:

(1) Elimination of connector pin pullout caused by most solid dielectric types.

(2) Shielding provided with most foam-dielectric cables result in lower rf leakage.

(3) Low attenuation.

(4) Long life span and low-maintenance requirements.

b. For more details on transmission lines, refer to section 3 of chapter 4.

18.-19. RESERVED.

CHAPTER 3. OPERATIONAL RELIABILITY AND AVAILABILITY CONSIDERATIONS

20. INTRODUCTION.

a. Reliability and availability have, in recent years, acquired distinct meaning and have grown into a full-fledged engineering discipline. The objective in this section is to establish methods and criteria for effecting improvements in reliability and availability of FAA communication systems. It does not discuss the mathematics involved or present detailed statistical analyses and prediction methods. However, some of the fundamental aspects of reliability and availability are discussed and the effect of equipment redundancy, emergency communications, alternate routing of circuits, and remote fault supervision on these factors is analyzed. Other methods, such as establishing intercom systems for maintenance purposes, routine maintenance, preventive maintenance, and standardization of methods, practices, and configurations, are suggested to reduce the system failure rate and system repair time, and to increase the system mean time between failure (MTBF) and the availability of the system.

b. Backup or standby radio transmitting and receiving equipment shall be provided for all FAA installations in accordance with the requirements in the latest edition of FAA Order 6510.4, Radio Communications Requirements for Air Traffic Control Facilities. Emergency backup requirements for FAA facilities are also specified in FAA Order 6510.4.

c. To demonstrate the improvement in reliability and availability due to equipment redundancy, some conceptual models that can easily be adapted to actual FAA systems are presented in this chapter.

21. SYSTEM EVALUATION.

a. Product Reliability. The reliability of a product is measured in relation to the mission it is to accomplish. In practice, it is never possible to accomplish this mission 100 percent of the time. This can be attributed to many factors, such as design shortcomings, material deficiencies, or cost limitations. In any event, the most important reason for considering reliability is to assure, with a measurable degree of confidence, that a system can accomplish its mission. Therefore, it is absolutely necessary to describe the mission clearly so that there is no doubt as to what must be achieved by the system and to indicate the cost within which the mission must be accomplished. Such a description must also include the tolerances which are to be allowed before the mission is considered a failure. When this is done, the systems engineer can specify the degree of reliability in terms of the operational conditions involved.

b. System Availability. A more important factor to be considered in an FAA communication system evaluation is system availability. While it would be ideal to have 100 percent system availability, it cannot be done because of equipment and manpower deficiencies and logistic and cost considerations. However, specific methods to improve the availability of a system, within these constraints, will be indicated in this discussion.

22. DEFINITIONS. To obtain a clear understanding of the concepts presented here, some simple definitions of the terms involved are given below.

a. Reliability (R). The reliability of an equipment or system is the probability of its survival over a given interval of time (t) during which no repairs are performed on the equipment or system. R is dependent on t.

b. Availability (A). Availability is the proportion of time that an equipment or system is available for use when averaged over a long interval of time. The assumption is that when an equipment fails, it is repaired or replaced and put into service again. A related factor, equipment or system unavailability, is defined as being equal to 1-A. Very often unavailability figures for a system give a better understanding of the effects of system improvement measures than availability figures.

c. Mean Time Between Failure. Mean time between failure (MTBF) is the average time between individual equipment failures in a large population of such equipment. The symbol M will be used to designate MTBF in the equations which follow.

d. Mean Time To Repair. Mean time to repair (MTTR) is the average time to repair an equipment after it has failed. In some environments the time to repair can be considered to be the time to replace the faulty unit with a good one. The symbol S will be used to designate MTTR in the equations that follow.

e. Source of Information on System Parameters. It normally would be possible to obtain approximate figures for equipment MTBF and MTTR from the equipment suppliers. If it is not, a careful analysis of the log books for the equipment, transmission lines, vf cables, etc., will give guidance on the values to be used for these in reliability and availability calculations. The period of time considered should be long enough to include at least five failures and repairs to equipment, transmission lines, or cables in order to place any reliance on the figures obtained.

23. GENERAL APPROACH TO SYSTEM IMPROVEMENT. A communication system is composed of several functional units, and the reliability and availability of this system are dependent upon the reliability and availability of these individual units and how they are configured. When selecting the equipment to fulfill the various functional system requirements, the planner can choose the equipment with the best MTBF from among those available in the market commensurate with cost. However, once the equipment for a system is selected, the reliability and availability of the system can be improved mainly by equipment redundancy and reduction of MTTR. However, every one of these alternatives (that is, choice of reliable equipment, equipment redundancy, and reduction of repair time) involves a cost penalty which must be carefully weighed before the most suitable system is chosen. Hence, there will be an emphasis on methods for system improvement that are within the control of the system designer, that is, by providing redundancy in the most economical way and by reducing MTTR through proper system design.

24. SINGLE EQUIPMENT CASE.

a. Though a single equipment is rarely used in the FAA environment, it is discussed here to provide a basis for the most complicated systems used in practice. For a single equipment, the reliability is expressed as:

$$R = \text{Exp}\ (-t/M) = \text{Exp}\ (-\lambda t)$$

where R is the reliability of the equipment, t is the duration of the mission or time interval indicated in paragraph 22a, M is the equipment MTBF, and λ is the failure rate $=1/M$. Note that R is time-dependent and decreases to zero when t is increased to a large value. In applying the formula, the same unit of time should be used for expressing t, M, and λ.

b. The expression for availability is:

$$A = \frac{M}{M+S} = \frac{\mu}{\lambda + \mu}$$

where A is the availability of the equipment; S is the MTTR of the equipment, μ is the repair rate = 1/S; and M and λ have the same meaning as above.

c. For an equipment with M = 1,000 hours and S = 10 hours, R and A for different values of t are given in figure 3-1. Note that while MTBF and R are intrinsic to the equipment and are outside the control of the FAA system planner, A can be improved by reducing S through better maintenance policies and by providing greater accessibility for equipment repair.

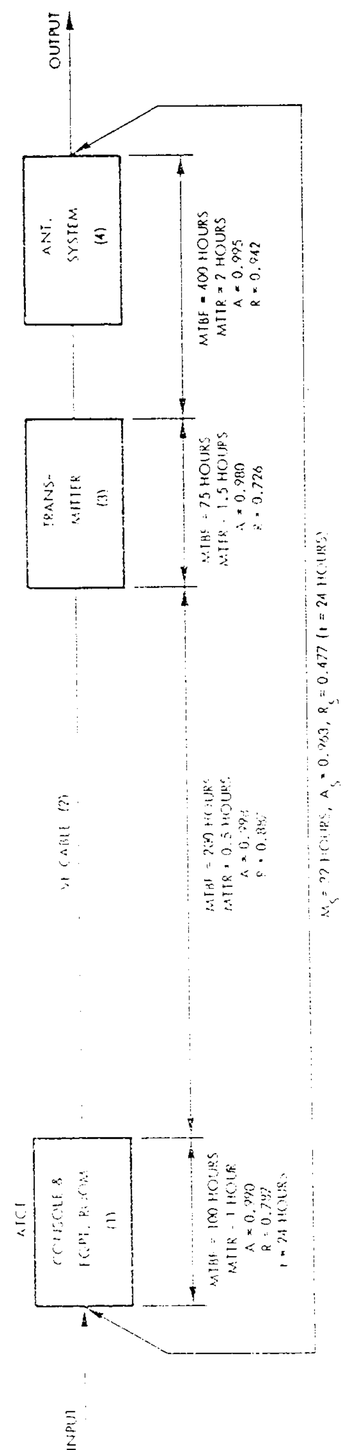
FIGURE 3-1. EXAMPLE OF RELIABILITY AND AVAILABILITY FOR SINGLE EQUIPMENT

T (hours)	1	10	100	1000	10000
R	0.999	0.99	0.905	0.37	0.5×10^{-4}
A		Constant at 0.99			

25. CONFIGURATIONS. In the FAA a-g communications system, several different equipment configurations are employed. The configurations reviewed are series, parallel redundant, standby redundant, and series-parallel, all of which occur in the FAA environment.

26. SERIES CONFIGURATION. When every equipment must be operating for the system to function in an acceptable manner, the equipment is considered to be in a series configuration. Figure 3-2 presents an example of a series configuration. The MTBF

FIGURE 3-2. SERIES COMMUNICATION MODEL



NOTE:
THE FIGURES FOR MTBF AND MTTR ARE NOT NECESSARILY REPRESENTATIVE OF ACTUAL VALUES. THEY HAVE BEEN SELECTED TO HIGHLIGHT THE POINTS UNDER DISCUSSION.

and MTTR of the individual equipment are shown in the figure. The constant long-term availability A and time-dependent R (for t = 24 hours) for individual equipment are computed by the formulas given in paragraph 24. The values on MTBF, R, and A for the complete series system can be computed from the following formulas:

$$\text{Series System MTBF } (M_s) = \frac{1}{\frac{1}{M_1} + \frac{1}{M_2} + \frac{1}{M_3} + \frac{1}{M_4}} = \frac{1}{\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4}$$

where the subscripts refer to the different equipment shown in figure 3-2.

$$\text{Series System Reliability } (R_s) = R_1 \times R_2 \times R_3 \times R_4 = \text{Exp } (-t/M_s)$$

$$\text{Series System Availability } (A_s) = A_1 \times A_2 \times A_3 \times A_4$$

The computed values of M_s, R_s, and A_s are shown in the figure. As the number of equipment increases, all of the above quantities decrease. Moreover, while A_s is independent of time, R_s decreases exponentially, approaching zero as time increases. Once the equipment comprising the system is selected, M_s and R_s are not within the system planner's control. A limited control on A_s can be had by designing the system to have low values of S_1, S_2, S_3, and S_4, the times required to repair or replace a faulty equipment, by suitable placement of equipment and proper maintenance techniques.

27. PARALLEL REDUNDANT CONFIGURATION.

a. Two or more pieces of equipment are considered to be in a parallel redundant configuration when any one of the parallel units can carry the load or fulfill the required system functions. An example of such a configuration is main and standby equipment, both of which are on (that is, in hot standby status), and the output of either one is acceptable for use. Since the parallel redundant configuration with two identical pieces of equipment is commonly used in FAA communication systems, the relevant formulas for this configuration are given below:

(1) Parallel Redundant System MTBF $(M_p) = \frac{3}{2} M + \frac{M^2}{2S}$.

(2) Parallel Redundant System Reliability $(R_p) = 2R - R^2$.

(3) Parallel Redundant System Availability $(A_p) = 2A - A^2$.

(4) Parallel Redundant System Unavailability is $1 - (2A - A^2)$.

b. To illustrate the striking improvement in the above quantities due to the parallel configuration, the computed figures for the quantities for the single equipment and for the parallel redundancy case are given in figure 3-3.

FIGURE 3-3. IMPROVEMENT DUE TO PARALLEL REDUNDANCY

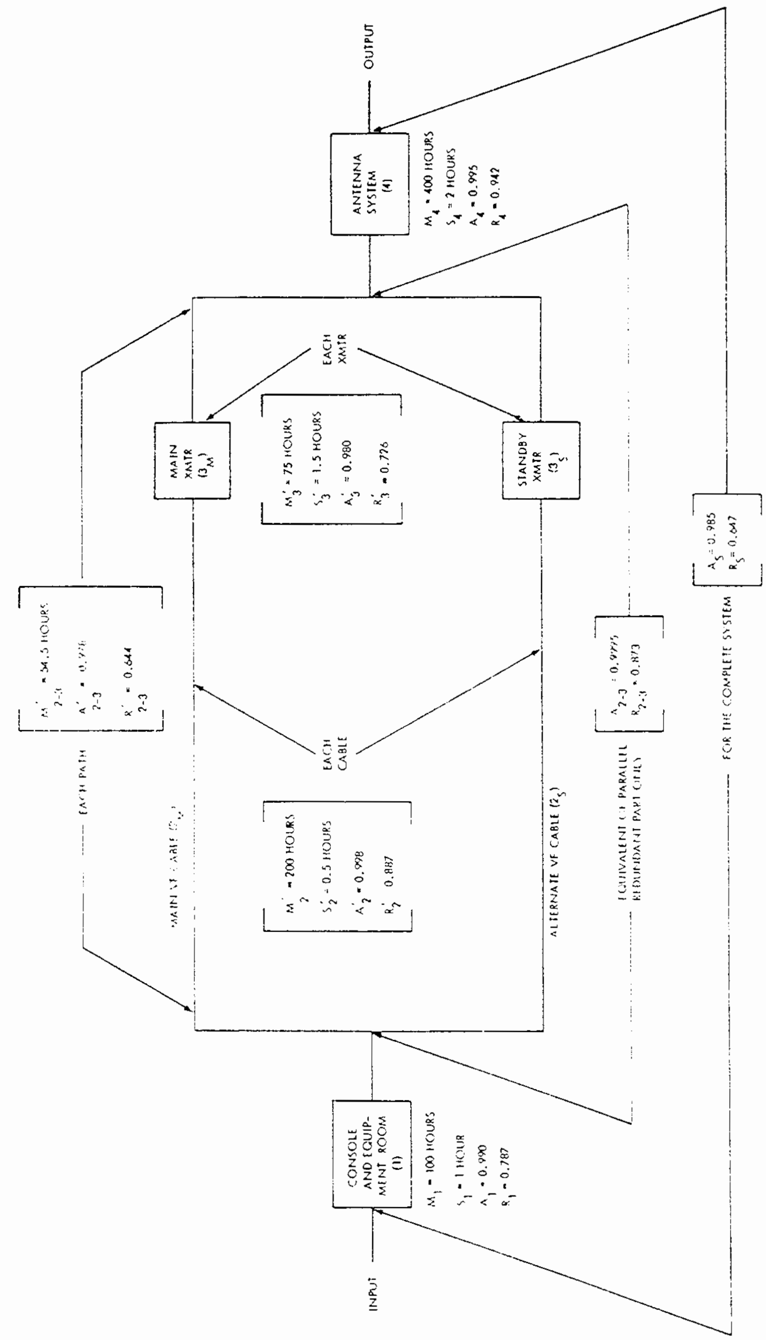
Measure	Single Equipment	Parallel Redundant Configuration
MTBF	1,000 Hours	51,500 Hours
Reliability (t = 1 week)	0.845	0.976
Availability (S = 10 Hours)	0.99	0.9999
Unavailability (in 100 days)	24 Hours	15 Minutes

c. Assuming that the above figures apply to a receiver, the unavailability figures show, for example, that with one receiver, the receiving facility will not be available for various periods totaling 24 hours in 100 days (a totally unacceptable situation), whereas the unavailability of the facility is reduced to fewer than 15 minutes in 100 days for two receivers in parallel. The cost increase ratio will be about 2. This would be cheaper than providing one receiver with an availability of 0.9999.

28. STANDBY REDUNDANT CONFIGURATION. This configuration differs from parallel configuration in that only one equipment (out of several in parallel) is on at any time. Though the standby equipment is ready to be switched-in for use, it is not actually on (that is, it is in a cold standby status). Note that while all the equipment in parallel configuration has the same failure rate (because they are all on), the off equipment in standby configuration has a lower failure rate than the on equipment. Evidently the system MTBF, reliability, and availability for this configuration will be better than that for parallel configuration. However, to take advantage of this better reliability and availability, the system planner will have to arrange for instantaneous remote switching on and off of equipment, besides changeover from main to standby equipment. Since this is usually quite expensive, the cold standby configuration is not normally used in FAA communication systems.

29. PARTIALLY REDUNDANT CONFIGURATION. An example of partially redundant configuration is shown in figure 3-4. This system is basically the same as the series configuration shown in figure 3-2 except that parallel redundancy has been provided for the vf cable and the transmitters. In all such cases, the parallel redundant portions of the system are analyzed first and replaced by equivalent single unit subsystems. The resultant series system is then easily analyzed.

FIGURE 3-4. PARTIALLY REDUNDANT COMMUNICATION SYSTEM



FOR COMPUTATION OF RELIABILITY (R), THE TIME (T) HAS BEEN ARBITRARILY CHOSEN AS 24 HOURS.

M = MTBF
S = MTTR
A = AVAILABILITY
R = RELIABILITY
THE SUBSCRIPTS 1,2,3 & 4 STAND FOR DIFFERENT UNITS
PRIMES ARE USED TO INDICATE FIGURES FOR EACH PATH OF PARALLEL CONFIGURATION
THE FIGURES FOR MTBF AND MTTR ARE NOT NECESSARILY REPRESENTATIVE OF ACTUAL VALUES.
THEY HAVE BEEN SELECTED TO HIGHLIGHT THE POINTS UNDER DISCUSSION.

Employing the same MTBF and MTTR figures for each equipment as in the simple series case, the availability and reliability of the complete system have been computed step by step and presented in the figure. Note that the unavailability of the system has decreased to less than one-half of the figure for the simple series case and the reliability has improved significantly. However, this improvement has been obtained at the cost of one more transmitter, one more cable, and the necessary switching equipment.

30. METHODS TO IMPROVE SYSTEM RELIABILITY AND AVAILABILITY. The reliability of a communications system can be improved by several techniques, some of which have been implemented by the FAA for establishing a set of standards to be followed at ATCT and en route facilities. These techniques are described in this chapter. In addition, new methods will be included that will contribute to system availability and improve existing service.

a. Maximizing Equipment MTBF/MTTR Ratio. All the foregoing formulas for reliability and availability of various systems indicate that to obtain a system of high reliability and availability, the individual equipment which makes up the system must itself have high values of R and A that are commensurate with cost. A high value of R for an equipment requires a high value of MTBF. An increase in value of A requires an increase in value of the ratio MTBF/MTTR. That is, MTBF must be maximized and MTTR minimized. Usually an increase in value of MTBF (which can be achieved with suitable equipment design (with better components and more complicated circuitry) involves an increase (not a decrease) in equipment repair time. Hence the MTBF/MTTR ratio for the equipment increases only slightly. It is apparent, therefore, that an equipment design which produces a high MTBF/MTTR ratio is likely to be expensive. Often a small increase in the ratio involves a disproportionate increase in cost.

b. Maximizing System MTBF/MTTR Ratio. In a communication system of a given configuration with equipment of known MTBF, the system MTBF is determined by analyzing the configuration as indicated in paragraph 29. Thus the system MTBF is fixed for that configuration. However, the MTTR of the system is, to some extent, within the control of the system planner. It can be reduced within limits by arranging to replace any faulty equipment with a hot standby and by repairing the former off-line, thus obtaining a high MTBF/MTTR ratio for the system. To do this, it is necessary to constantly or at least frequently monitor both on-line and off-line (hot standby) equipments and provide a warning if any equipment fails.

c. System-Versus-Equipment Reliability and Availability. If a configuration consists of a mixture of low- and high-reliability equipment, it can be shown that improving weaker equipment reliability results in a more significant increase in system reliability than if the stronger units are improved. Thus, strengthening the reliability of the weaker units is economical. The same considerations also apply to system availability. In addition, any measure which increases the MTBF/MTTR ratio of the system, such as the one indicated in paragraph 30b, will directly improve the system availability.

d. Equipment Redundancy. One way of improving system reliability and availability is to provide redundancy for the weaker equipment. It is often less expensive to have, say, two or more pieces of equipment of low reliability in redundant configuration than to provide a single equipment of equivalent higher reliability. What degree of redundancy should be provided for each equipment can be determined by making a cost-effectiveness study to achieve the required reliability and availability.

e. Cable Redundancy. Providing a redundant cable also improves system reliability and availability. But an essential requirement of parallel redundant configuration is that the system should have the capability to switch from main to the alternate cable instantaneously. Any arrangement not providing this instantaneous switching capability (such as the need for patching jack panels to change over from main to alternate cable) will increase the effective MTTR and reduce the availability very significantly. The latest edition of Order 6510.4, Radio Communications Requirements for Air Traffic Control Facilities, details requirements for cable redundancy.

f. Redundancy of Remotely Located Units. Since it usually takes more time to repair or replace a remotely located unit than a local unit, it is more advantageous to build parallel redundancy in such remote units than in local units. The effective repair/replacement time is the total time required (1) to determine that the faulty unit is in the remote facility, (2) to reach the remote facility if it is unmanned, (3) to replace the faulty unit, and (4) to test the system or part of the system before placing the unit into service. A valuable configuration results by placing the main transmitters and receivers at the remote sites and standby equipment at the ATCT. In this configuration the standby equipment is not subject to the same contingencies as the equipment at the remote sites. Another possibility warranting investigation is to locate a number of transmitter units at a receiver site and vice versa. With this configuration, in the event of a total failure at one station, communications will not be totally disrupted.

g. Other Forms of Redundancy. If antenna multicouplers are utilized to interconnect several receivers to the same antenna, or if hybrids are used to couple several transmitters to one antenna, main and standby equipment on the same channel should not share a common antenna. This is necessary to avoid a system where damage to one antenna will put a channel out of service entirely. If multicouplers or hybrids are used in a system without backup transmitters and receivers, a second antenna should be provided for backup with automatic switchover. This is necessary since damage to one antenna will put several channels out of service at the same time. Separate antennas on main and standby equipment are recommended. To decide which units should be made redundant in a system, some well-known methods can be used. One of these procedures, the Kettele Method, not only considers the reliability of each unit as a criterion, but also takes the cost of the unit into account. The net result would be to make redundant those units that are most unreliable and least expensive. For FAA installations, the guidelines set forth can be utilized to achieve the desired reliability, and a tradeoff between cost factors and overall availability improvement can be evaluated.

h. Automatic Switchover. All redundant units must be equipped with an automatic switchover feature or a remote-switching capability in the tower cab. Thus, if a main unit fails, the standby unit can take over and restore service continuity, thereby reducing switching time and increasing system availability. The switching unit may be a relay or an electronic switch, either of which is commercially available and, in newer equipment models, is an inherent part of the system. The automatic switchover feature must include the standby generators at remote sites. At most existing RTR sites with emergency generators, the generators start automatically and take over the equipment load when there is a failure of commercial power. The provision for emergency power is covered by the latest edition of Orders 6030.20, Provisions of Electrical Power for National Airspace System Facilities, and 6950.2, Power Policy Implementation at National Airspace System Facilities.

i. System Status Alarm and Supervisory Panel. To reduce outage time, the maintenance crew must be alerted to any system abnormality as soon as a failure occurs. The most efficient way of monitoring facility performance for unmanned remote stations is to bring in status signals from the major equipment and display them continuously on a supervisory panel located at the maintenance center (equipment room) where around-the-clock attendance is available, and/or at the tower cab in smaller airports. When a failure occurs, a lamp on the panel illuminates, thereby notifying personnel of a malfunction so that proper action can be taken to clear the fault. A contract was awarded in 1981 for installation and provision of equipment which will provide remote maintenance monitoring for RCAG locations. An expansion of this monitoring system is planned at other remote sites, depending upon initial satisfactory results and availability of funds.

j. Maintenance Intercommunication System. A recent site survey of FAA facilities revealed that the commercial telephones located in the tower, ATCT equipment room, and remote sites were the primary means of communications available to coordinate maintenance activities. Reliance on the telephone system for maintenance of fail-safe communications is hardly the ultimate solution. Since reliability of communications is so essential to maintenance activities, reliance should not be placed on the telephone system for these activities. It is recommended that the primary means of communications be via a two-way intercom or radio system, when applicable, with stations connected on a full-time party line basis. The commercial telephone system should be maintained as a backup in case of intercom failure.

k. Emergency Communication Equipment. Emergency air-to-ground communications are provided by uhf and vhf transceivers. Remotely controlled transceivers are used to support ARTCC locations. Portable transceivers are used to support ATCT and FSS locations. Such emergency equipment is used to insure continuous (no-break) service in the event of catastrophic failures of primary and secondary systems. Ideally, the portable transceivers should have self-contained battery packs, antennas, and digital readout of frequency. It should be possible to install these units in a vehicle that can quickly move away from the tower and establish communication channels for control of air traffic in the event of total failure of tower cab facilities, bomb threats, or other emergencies. Remotely tuned transceivers used in support of ARTCC locations are located at sites other than those that support primary and secondary systems.

l. Electrical Power Policy. The latest editions of Orders 6030.20 and 6950.2 establish policy and provide implementation guidance for electrical power systems supporting NAS. These orders designate airports which must be provided with continuous power and specify types of services (commercial, standby engine generators, standby battery, etc.) to be provided for each type of facility.

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32.-34. RESERVED.

CHAPTER 4. TECHNICAL FACTORS AFFECTING AIR-GROUND COMMUNICATIONS

SECTION 1. PROPAGATION

35. SCOPE. This section includes a discussion of vhf/uhf propagation theory, antennas, transmission lines, noise, interference, and methods of eliminating interference. Additional information on these subjects can be found in the FAA Technical Center Report No. FAA-RD-71-76, VHF/UHF Ground/Air/Ground Communications Siting Criteria; Ultra High Frequency Propagation, H.R. Reed and C.M. Russell; and Order , Antenna Configuration Handbook for Terminal and En Route Facilities.

36. PROPAGATION ZONING.

a. General. The propagation problems involved in vhf/uhf service ranges for air-to-ground and ground-to-air communications primarily result from lobes caused by the interaction between direct and ground-reflected rays as well as from a systematic decrease in free-space maximum range with increasing frequency. In addition, factors such as frequency, distance, antenna heights, curvature of the earth, atmospheric conditions, and the presence of hills, buildings, trees, and other obstructions can seriously affect and distort a transmission path. In this section, propagation aspects of vhf frequencies from 100 to 150 MHz and uhf frequencies from 225 to 400 MHz will be of main concern. Since most radio paths cannot be considered to be free-space paths, it is necessary to determine the effect of perfectly flat earth, and then the effect of earth curvature. Obstructed paths are not considered desirable and must be avoided by suitable siting. The effect of obstructions in the transmission path will be covered later.

b. Free-Space Propagation.

(1) Consider the transmitter and receiver of a communications system to be in free space with no ground or obstructions influencing the path between them. Such a free-space transmission path would be a straight line in a vacuum or ideal atmosphere, and would be sufficiently removed from all objects that might absorb or reflect radio energy. Under these conditions, several well-known fundamental relationships exist between transmitter power, antenna gain, field strength, receiver sensitivity, and maximum range of communications.

(2) The field strength due to a source varies inversely as the distance from the source. Furthermore, the field strength at any point in space from an antenna radiating a given amount of power with a given radiation pattern is independent of frequency. The free-space field strength (intensity), E_o, at a distance, D meters, from a transmit antenna is given by:

$$E_o = \frac{\sqrt{30\ GP}}{D} \text{ volts per meter}$$

where P = radiated power, watts
G = power gain ratio of the transmit antenna
D = distance from the antenna, meters

The maximum power collected by a half-way dipole antenna from a radiation field of given intensity is inversely proportional to the square of the frequency. If this inverse square frequency relationship is combined with the inverse distance relationship of field strength expressed in the above equation, then the free-space loss variation with frequency and distance, expressed in decibels between two half-wave dipole antennas oriented to each other for obtaining maximum transmission, is expressed mathematically as:

$$L_f = 32.3 + 20 \log_{10} f + 20 \log_{10} D$$

where L_f = free-space propagation loss, dB

f = frequency, MHz

D = distance, statute miles

For isotropic antennas this equation becomes:

$$L_f = 36.6 + 20 \log_{10} f + 20 \log_{10} D$$

Figure 4-1 is an easy-to-use nomogram for determining free-space transmission loss between isotropic antennas.

(3) It follows from these considerations that all other things being equal, the free-space maximum range for a-g communications systems is inversely proportional to frequency.

c. Propagation Over Smooth Earth. The presence of ground modifies the propagation of a radio wave so that the received field intensity is ordinarily less than would be expected in free space. The ground acts as a partial reflector and absorber, and both of these properties affect the distribution of energy in the region above the earth.

(1) Over a smooth spherical earth, the space wave at the receive antenna is composed of a direct wave (corresponding to the free-space wave) and a ground-reflected wave. Figure 4-2 shows the physical representation of these waves. The space-wave field strength is the vectorial sum of the direct and ground-reflected wave fields. For 100 percent reflection over a plane surface, it would vary between zero and twice the free-space value from lobes in vertical cross section. The positions of the lobes would depend on the antenna height above ground, frequency, and, to a lesser extent, polarization and ground constants. Figures 4-3 through 4-8 illustrate these lobes.

(2) The communications system loss, assumed to be 6 dB in figures 4-3 through 4-8, includes the antenna-to-transmitter cable loss, antenna-to-receiver cable loss, and the deviation in antenna gain from that of a dipole.

(3) In the vhf/uhf region of the radio spectrum, transmission is through the atmosphere, and hence, ionospheric phenomena, so important to long-range communication at the lower frequencies, do not occur. Absorption by rain, or other forms of precipitation, or by the atmosphere itself is negligible at vhf/uhf frequencies.

FIGURE 4-1. FREE-SPACE TRANSMISSION LOSS BETWEEN ISOTROPIC ANTENNAS

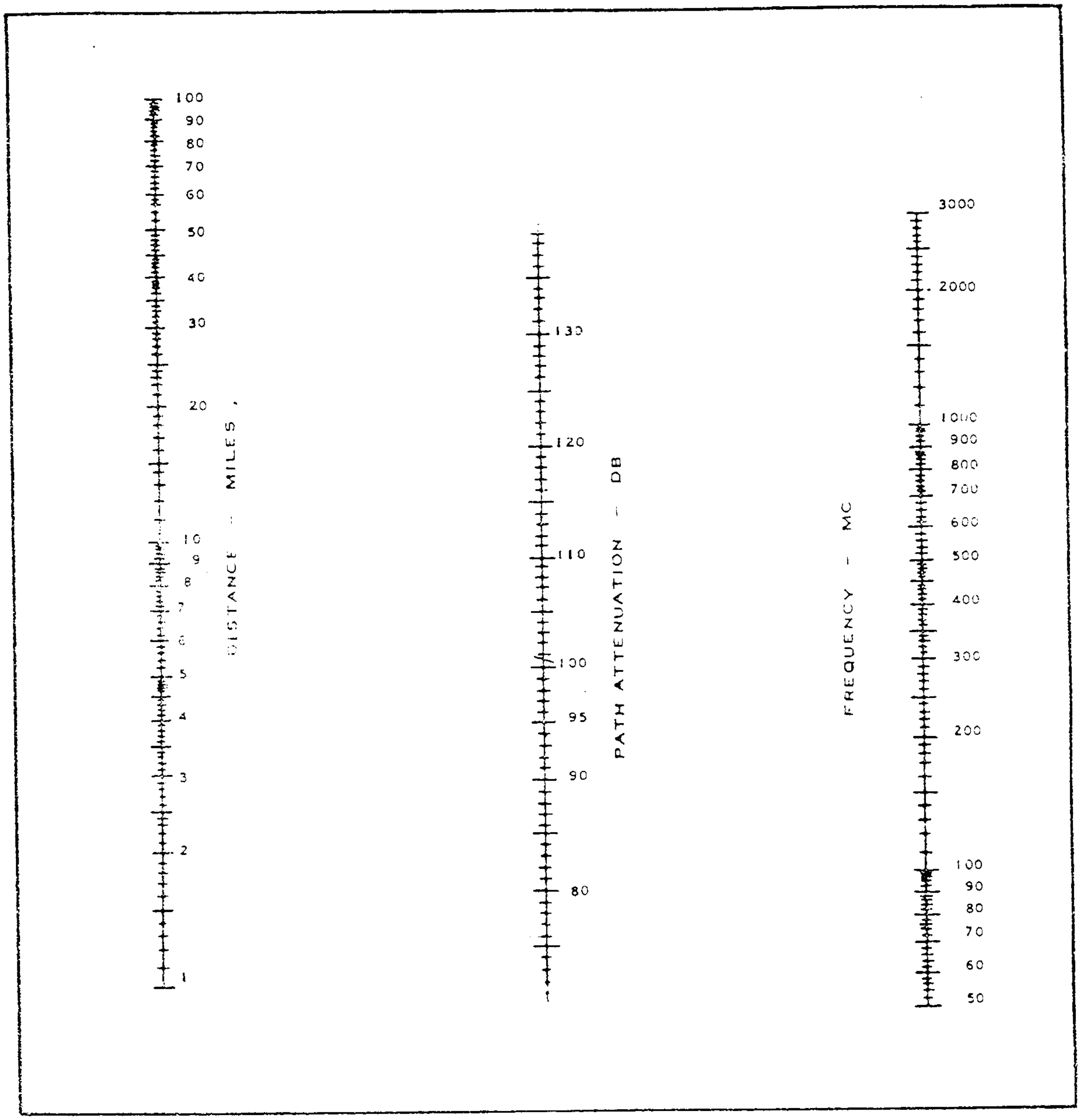


FIGURE 4-2. DIRECT AND REFLECTED RADIO WAVES

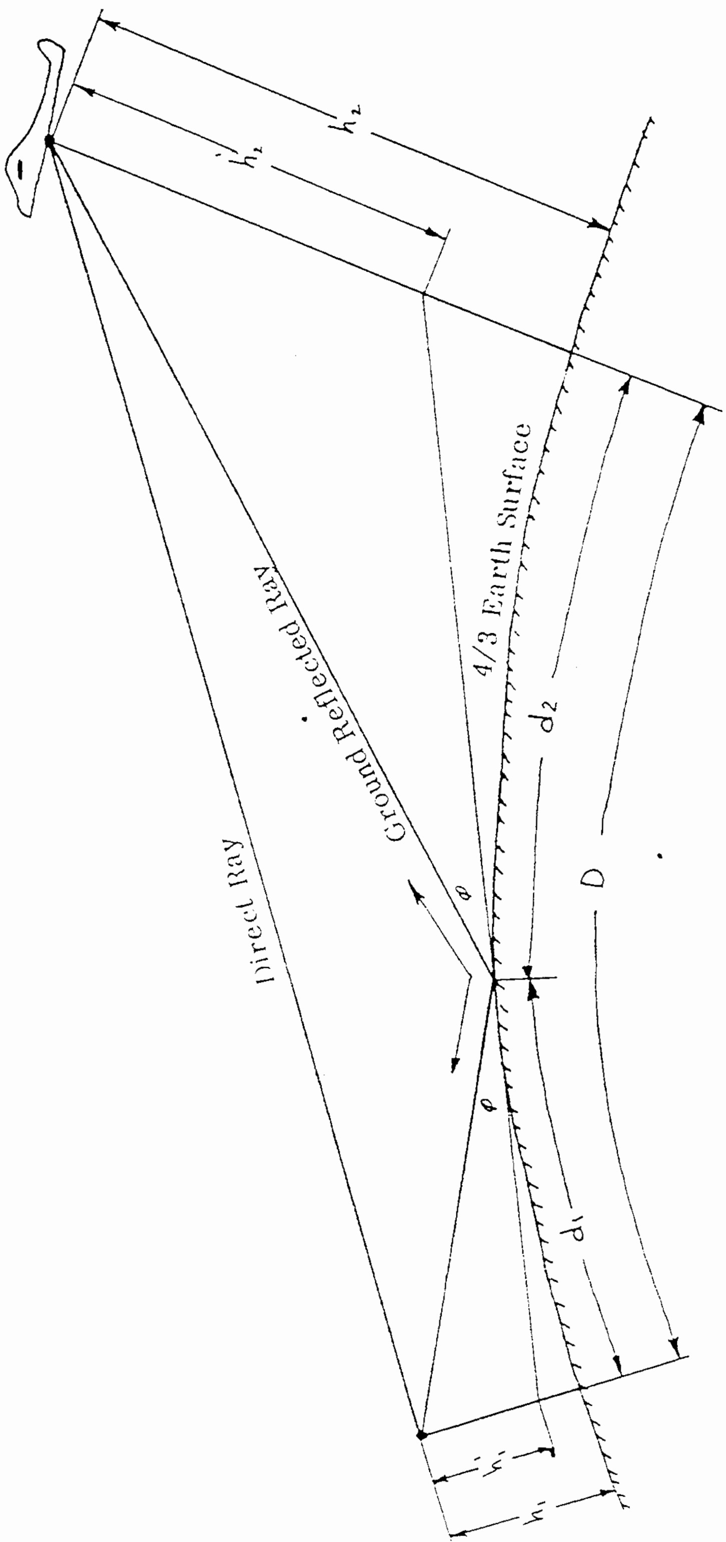
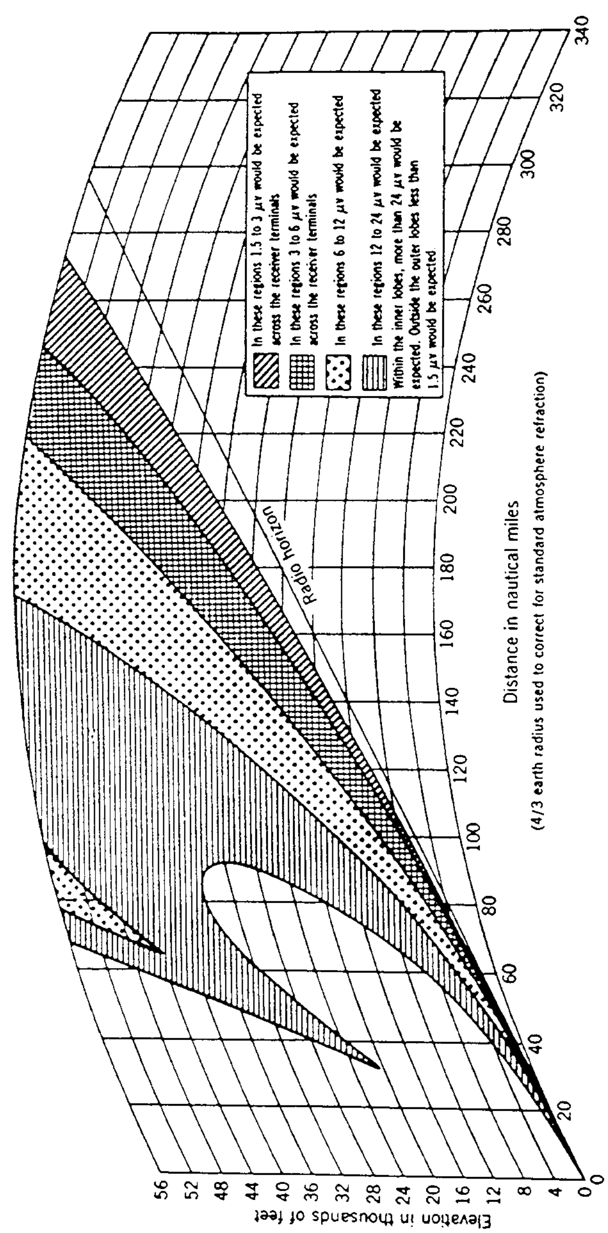


FIGURE 4-3. THEORETICAL VHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER A SMOOTH SPHERICAL EARTH. 139.14 MHz/sec.



Transmitting antenna: Half-wave vertical dipole
Receiving antenna: Half-wave vertical dipole

Effective height ground antenna: 35 feet
Assumed communication system loss: 6 db
Free space maximum range for 6-watt transmitter and 1.5 μv at receiver terminals: 878 nautical miles

Voltage contours are microvolts input to receiver terminals
Transmission over land.

FIGURE 4-4. EXPERIMENTAL VHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER LAND. 139.14 MHz/sec.

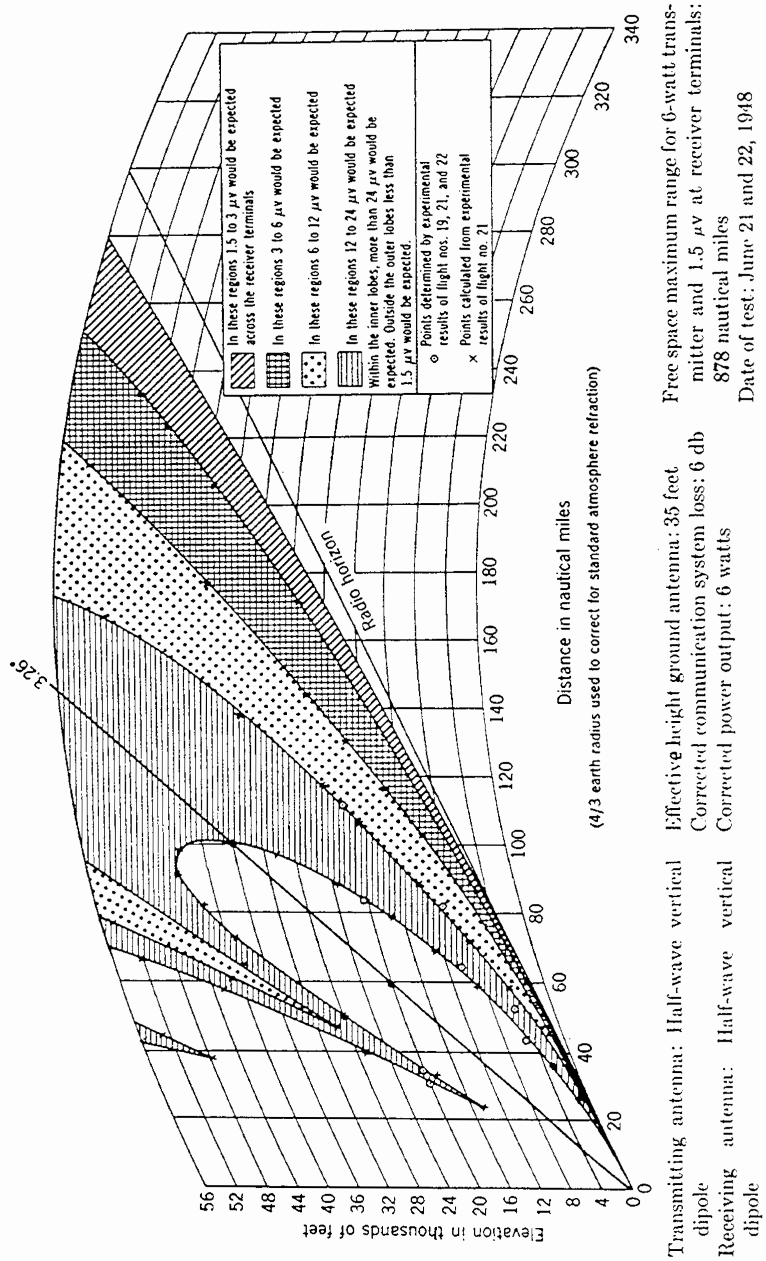


FIGURE 4-5. THEORETICAL UHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER A SMOOTH SPHERICAL EARTH. 328.2 MHz/sec.

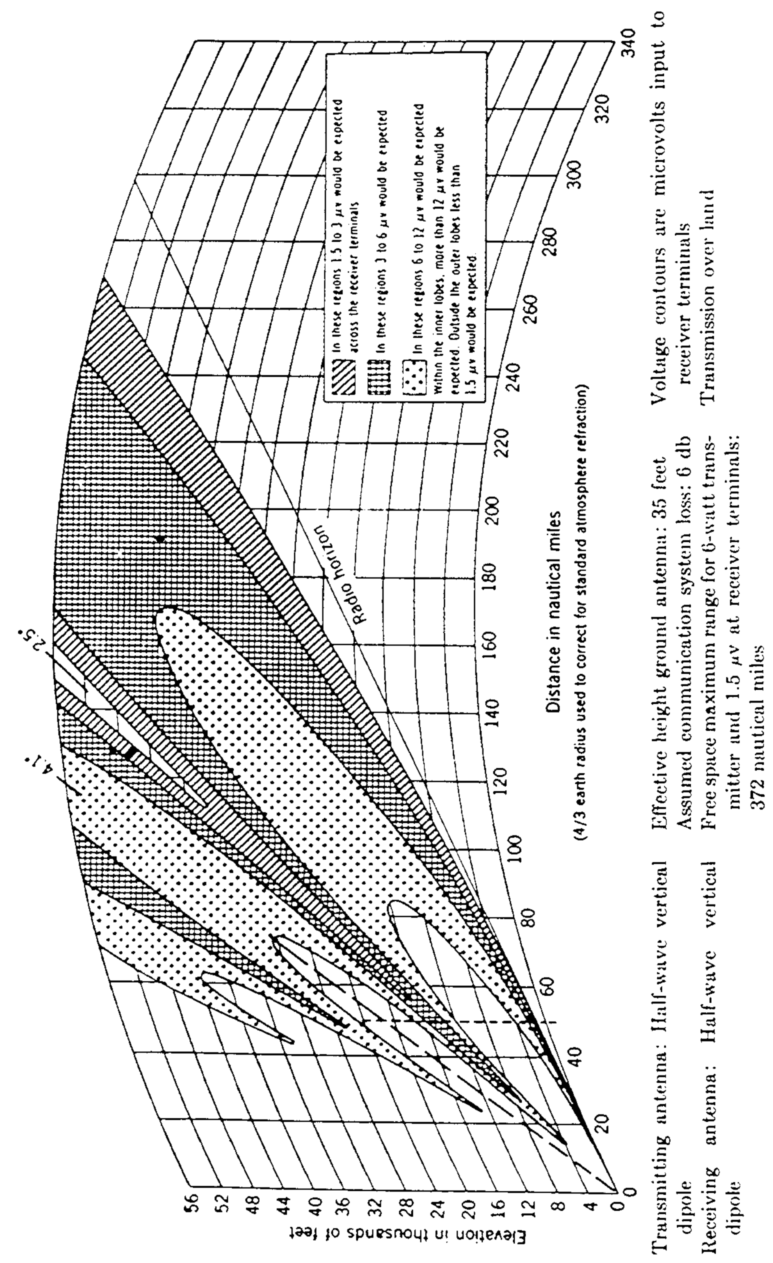


FIGURE 4-6. EXPERIMENTAL UHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER LAND. 328.2 MHz/sec.

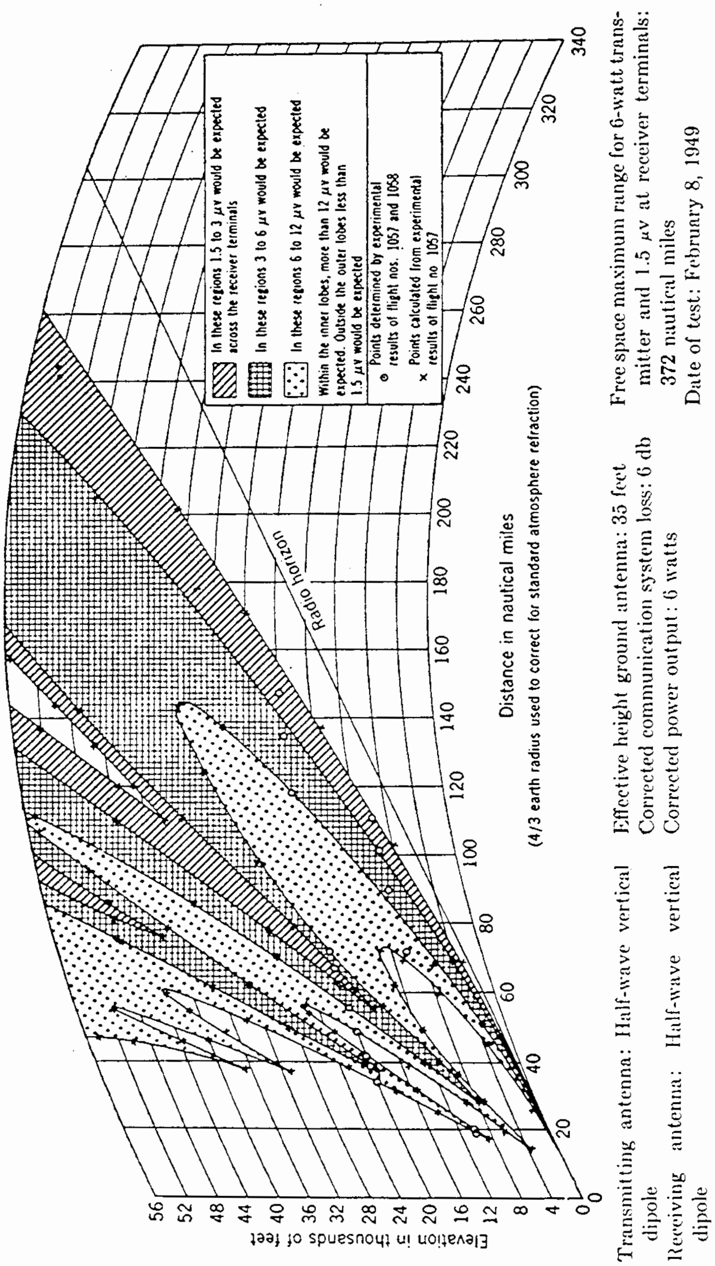


FIGURE 4-7. THEORETICAL VHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER WATER - SMOOTH SPHERICAL EARTH MODEL. 243 MHz/sec.

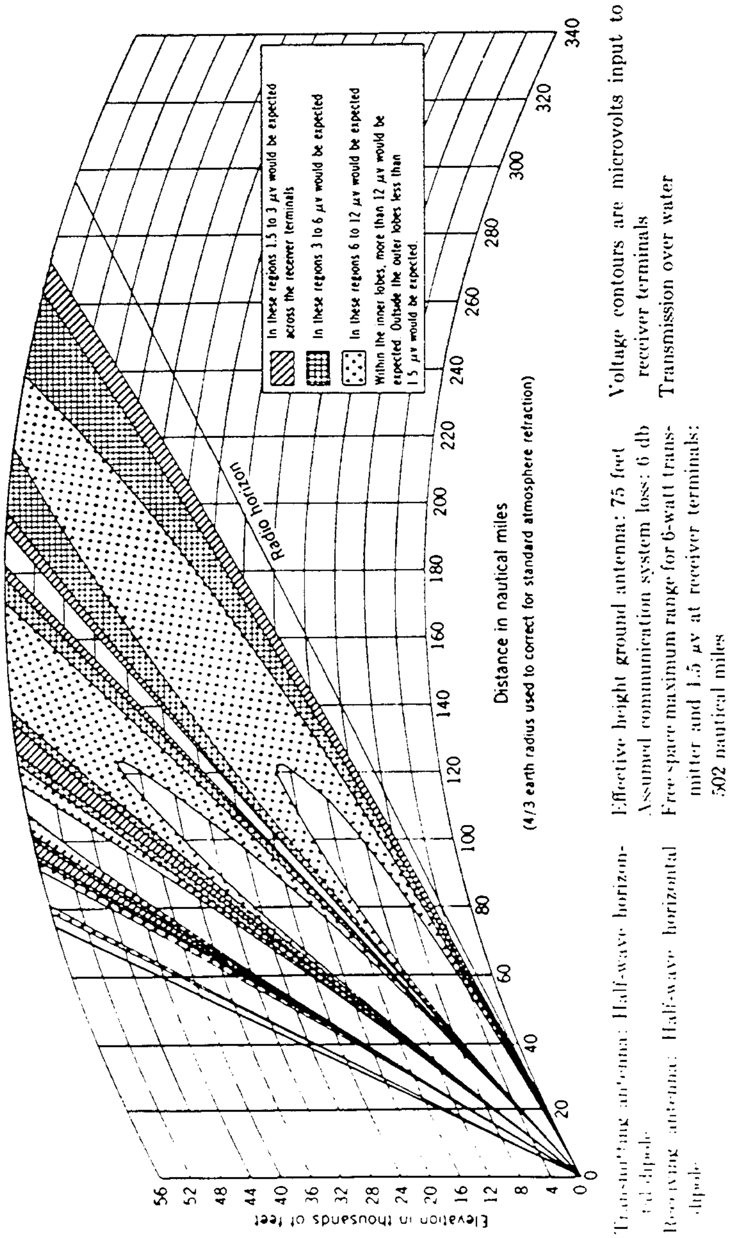
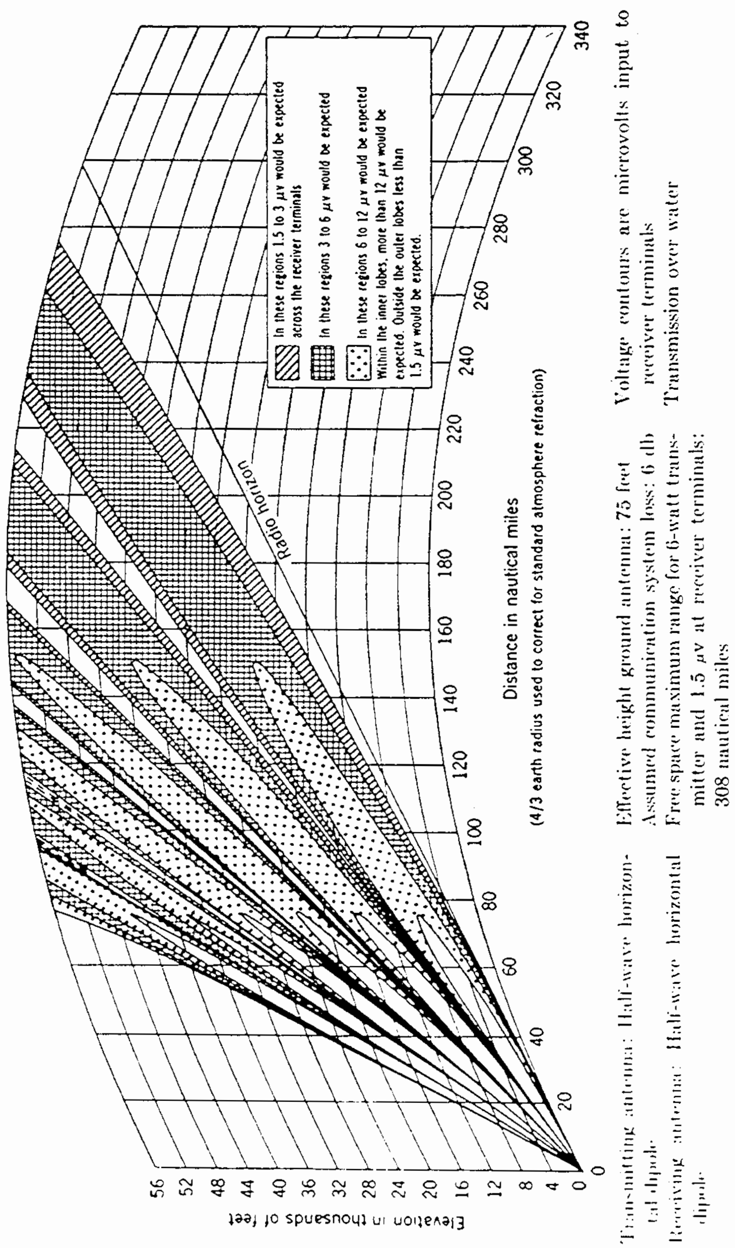


FIGURE 4-8. THEORETICAL UHF RADIATION PATTERN, AIR-TO-GROUND COMMUNICATION OVER WATER - SMOOTH SPHERICAL EARTH MODEL. 396 MHz/sec.



(4) The usual concept of radio waves is that the waves travel in straight lines from the transmit antenna to the receive antenna. Such an assumption may lead to large errors and certainly will not account for some of the seemingly impossible ranges obtained in many instances. A part of this increase in distance is because of the fact that radio waves are bent away from a straight line path by refraction in the atmosphere. This curvature of a ray path is controlled by the angle of incidence on the refracting layer and by the rate of change of the refractive index, where the refractive index is a function of temperature, pressure, and moisture content of the atmosphere. In a nonstandard atmosphere, a sudden change or discontinuity in refractive index with height may form a reflecting surface capable of reflecting a sizable amount of incident energy, if the grazing angle between the wave and the boundary surface is sufficiently small. In a standard atmosphere the normal finite change of refractive index with height acts as an infinite number of infinitely small boundary layers, each layer reflecting an infinitesimal amount of energy. The net result for a radio wave passing through such a uniformly stratified atmosphere at a small grazing angle is that the wave is continuously robbed of minute amounts of energy which are lost by reflection.

(5) Radio waves deviating from a straight line is a condition known as diffraction. Whenever radio waves encounter an obstructing object, some of the energy of the wave is diffracted at the edge and bends around the edge. This reduces the shadowing effect of the objects which are opaque to radio waves, as diffraction fills part of the shadow area with some energy from the wave. The curved surface of the earth is the edge of one such object. Other objects may be buildings, trees, hills, mountains, masts, and structural parts of a ship, or the wings, tail, or other parts of the airplane. If the obstructing object is small and subtends only a small angle, as seen from the source of radiation, the region at a considerable distance behind the object may become filled in and suffer little or no shadowing effect. Close to the object, however, shadowing will be present. Shadowing due to the earth causes the field strength to decrease rapidly with distance beyond the radio horizon.

(6) The problem of calculating radiation patterns at vhf and uhf, therefore, includes consideration of the following nontime-varying factors:

(a) Gain and directivity of ground and airborne antennas.

(b) Reflection and diffraction phenomena associated with the surface of the earth.

(c) Refraction and reflection produced by nonhomogeneous regions of the atmosphere (other than the ionosphere).

d. Irregular Terrain.

(1) For simplicity in figure 4-2, ground-reflected rays are shown to occur at a point. Actually, the entire surface of the earth is illuminated and radiates elementary waves in all directions. Over smooth earth, at any particular receiving location, the resulting intensity of these waves very nearly equals that of the waves reflected from within a small elliptical area in the neighborhood of

the ray reflection point determined by the laws of geometric optics. This elliptical area is called the first Fresnel zone. The intensity and phase relationships of the remaining waves reflected from beyond the first Fresnel zone very nearly cancel each other out. The length of the ray path to the edge of the entire first Fresnel zone is one-half wavelength longer than the geometrical ray path. The dimensions of this elliptical area are shown in figure 4-9 and are given below:

$$X = \frac{H}{\tan \phi}$$

$$Y = \frac{-\lambda \cos \phi + \sqrt{\lambda^2 \cos^2 \phi + 4H\lambda \sin \phi}}{2\sin^2 \phi}$$

$$Z = \frac{+\lambda \cos \phi + \sqrt{\lambda^2 \cos^2 \phi + 4H \lambda \sin \phi}}{2 \sin^2 \phi}$$

$$W = 2\sqrt{\frac{\lambda H}{\sin \phi}}$$

where the dimensions X, H, Y, Z, and W are expressed in feet and are as shown in figure 4-9. Wavelength, λ , and antenna height, H, are expressed in feet, and radiation angle, ϕ, is the grazing angle. Within this zone, irregularities in terrain would be expected to have the greatest effect on the reflected signal. For low-radiation angles, this area could be fairly large. For example, a vhf antenna mounted on a 75-foot tower and operating on 125 MHz with a 2-degree radiation angle would result in an ellipse having the following dimensions:

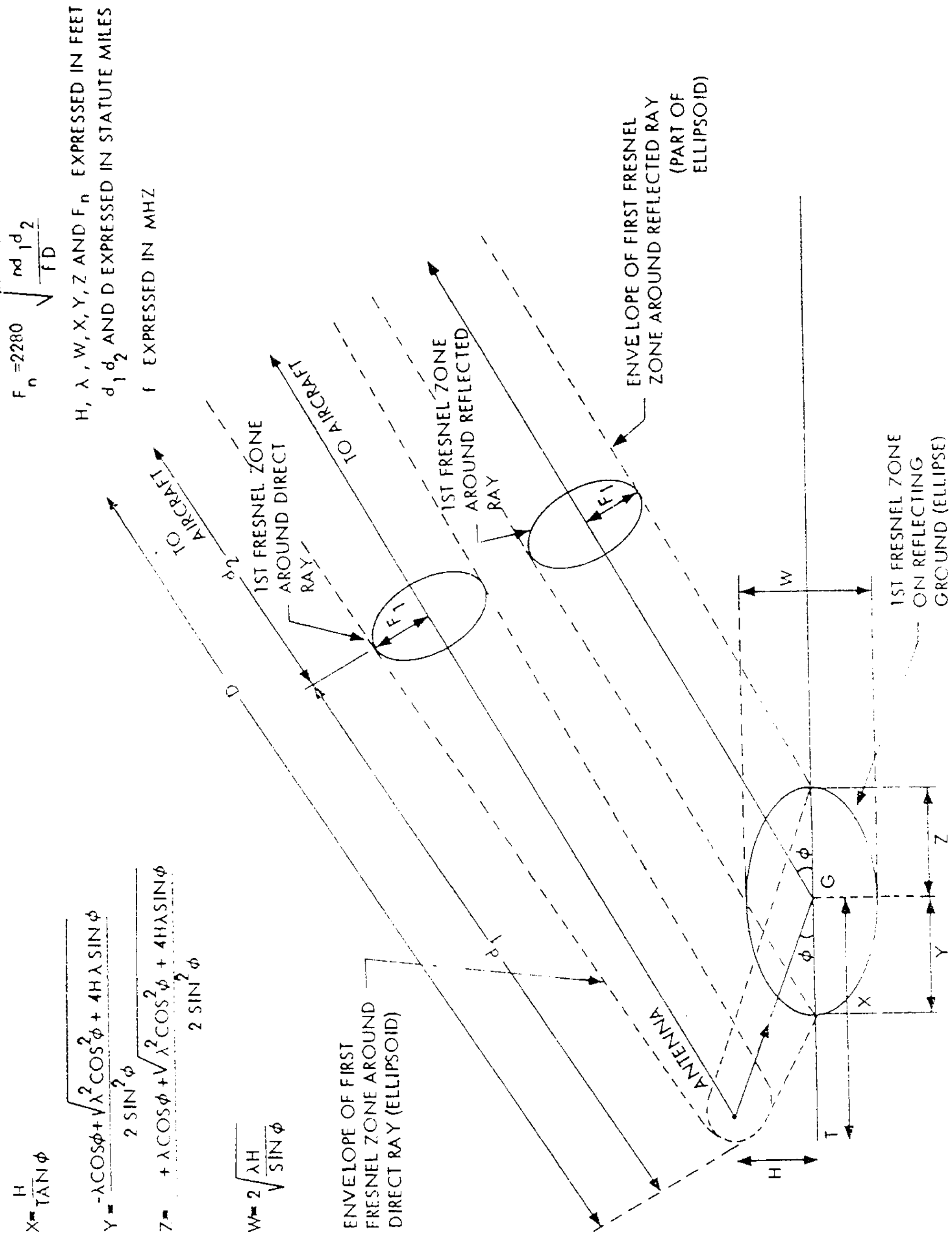
X = 2,148 feet, Y = 1,170 feet, Z = 8,267 feet, and W = 262 feet.

That is, the ellipse extends up to a distance of 8,267 + 2,148 = 10,415 feet from the foot of the tower, or approximately 2 miles.

(2) In general, the effect of irregularities in the reflecting ground surface causes filling-in of the lobe minima and a lesser development of the lobe maxima.

e. Clearance Over Obstructions. To complete the strength of a signal at any point in space, it is necessary to consider the effect of obstructions in the path of the direct and reflected waves. The wave energy passing through the first Fresnel zone surrounding the direct and reflected waves contributes the maximum amount to the signal strength at the receive point. Contributions from other Fresnel zones gradually diminish and to some extent cancel one another. Hence, the number of Fresnel zones to be considered in computing signal strength is a matter of discretion, depending on the accuracy required. The boundary of the n^{th} Fresnel zone consists of all points on which the path length differs from the geometrical ray path length by n/2 wavelengths. The n^{th} Fresnel zone radius, in feet, for any point along the direct or reflected ray path is given by

FIGURE 4-9. FRESNEL ZONES FOR DIRECT AND GROUND-REFLECTED RAYS



$$F_n = 2280\sqrt{\frac{nd_1\ d_2}{f\ D}}$$

where n = zone number

f = frequency, MHz

D = total path length, statute miles

d_1 = distance in statute miles of the point from the antenna where the radius of the n^{th} Fresnel zone is required (see figure 4-9)

d_2 = $D - d_1$, statute miles.

f. Antenna Height For A Clear Site. In determining the antenna height for a site having no obstructions, the minimum height should be chosen that provides the required maximum range at low-elevation angles and gapless coverage at higher angles. The technique for doing this is presented in Order 6630.3 , Antenna Configuration Handbook for Terminal and En Route Facilities, Appendix 2.

g. Transmission Over Obstructions.

(1) The preceding discussions assume that the earth is a perfectly smooth sphere. Effects caused by hills, trees, and buildings are difficult to compute, but the order of magnitude of these effects can be determined from considering another extreme case, that is, propagation over a perfectly absorbing knife-edge. The diffraction of plane waves over a knife-edge or screen causes a shadow loss whose magnitude may be found from figure 4-10. This nomogram assumes that ground reflections do not contribute significantly to the total received signal.

(2) The height of an obstruction, H, is measured from the line joining the two antennas to the top of the obstruction, as indicated in figure 4-11. Shadow loss is negligible when the line joining the two antennas is well above the obstruction providing a clearance of several Fresnel zones (H is negative). The loss gradually increases until it approaches 6 dB as H approaches zero (grazing incidence), and it continues to increase with increasing positive values of H. Taking earth curvature into consideration, H, in feet, is given by

$$H + H_o - \left[\frac{H_B d_1 + H_A d_2}{D} - \frac{d_1 d_2}{1.5K}\right]$$

where H_A = Height of antenna above mean sea level (AMSL), feet

H_B = Height of aircraft AMSL, feet

H_o = Height of obstruction AMSL, feet

d_1 = Distance of obstruction from antenna, statute miles

D = Distance of aircraft from antenna, statute miles

d_2 = $D - d_1$, statute miles

K = Equivalent earth radius factor (usually taken as 1.33 for vhf and uhf bands)

FIGURE 4-10. SHADOW LOSS RELATIVE TO FREE SPACE

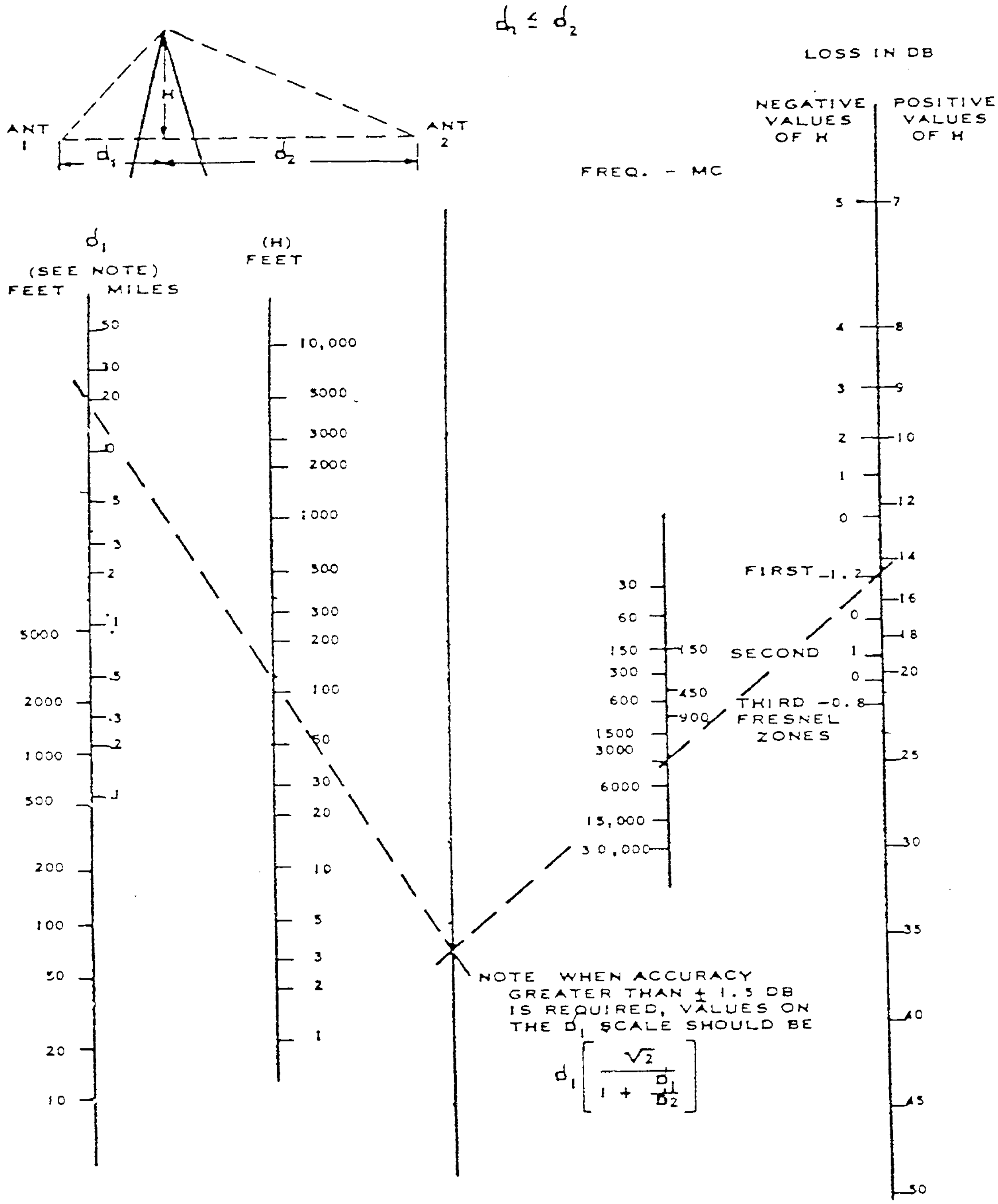
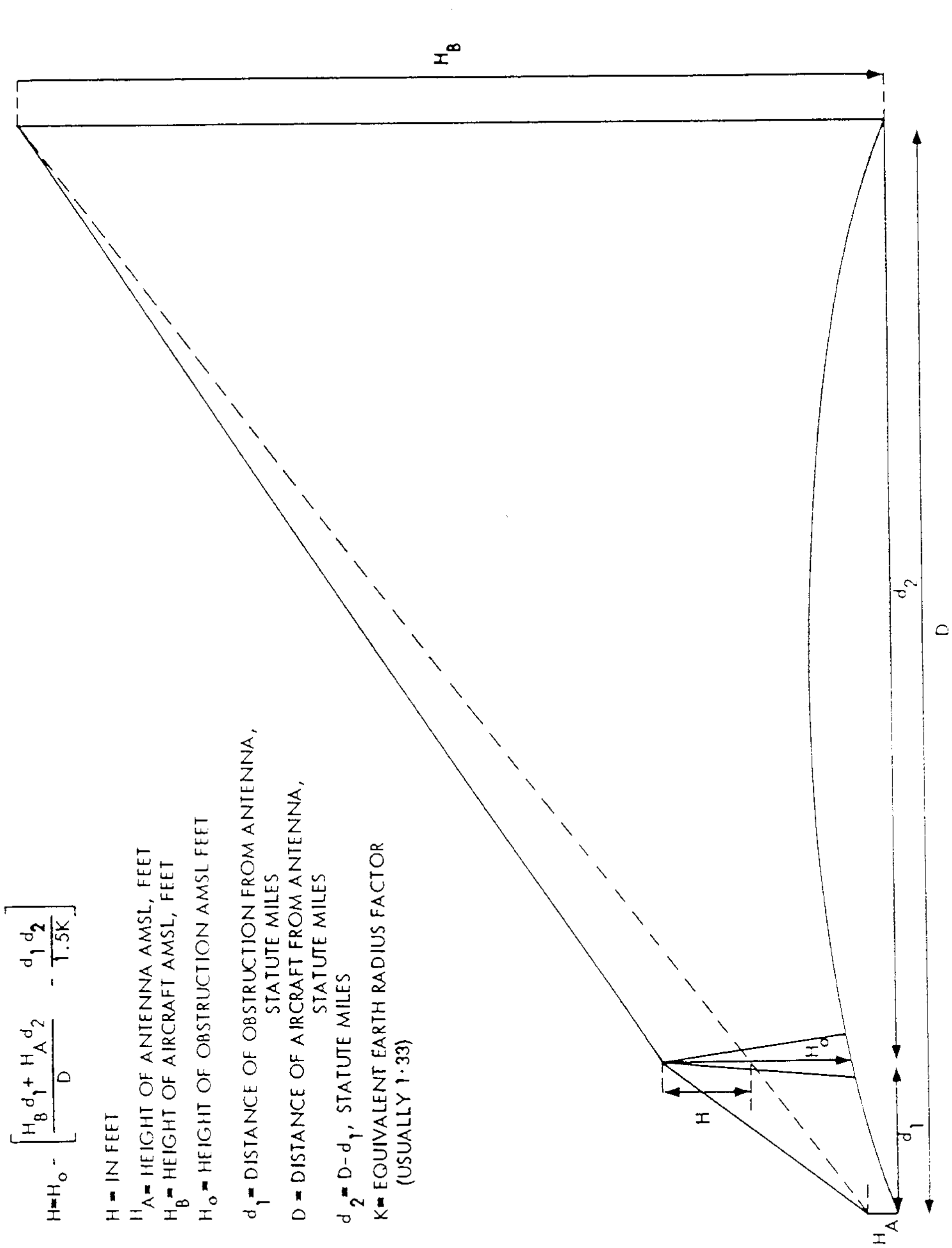


FIGURE 4-11. OBSTRUCTED RADIO PATH



If both the direct ray and the ground-reflected ray clear the obstruction by several Fresnel zones, vertical lobes will occur, and figure 4-10 should not be used. Vertical lobing should be analyzed as indicated in Order 6630.3, Antenna Configuration Handbook for Terminal and En Route Facilities.

h. Fading. Fading is difficult to predict and the general practice at microwave frequencies is to consider fading on a statistical basis, using a Rayleigh distribution to describe the signal fluctuations. At the lower frequencies with which we are concerned, the effect of inverse bending and multipath, which cause microwave fading, are much less. Putting it another way, for the same atmospheric abnormality, the effect on the lower frequency is less because of the longer wavelength. Figure 4-12 shows fading range as a function of frequency for 90, 99, 99.9, and 99.99 percent of the time. As a first-order approximation, the fading range can be varied directly as a function of distance but never exceeding the Rayleigh distribution. Figure 4-12 has been plotted for typical 30-to-40 mile los paths.

37. SYSTEM ENGINEERING SAMPLE CALCULATIONS.

a. The performance of an a-g communications system is best explained by means of a typical example. To find the propagation reliability factors we can expect from such a system, the following assumptions are made for a hypothetical example:

Ground transmitter power	10 watts
Receiver input impedance	50 ohms
Airborne receiver sensitivity	87 dBm level for 10 dB S/N
Center frequency	120 MHz
Operating range	40 miles

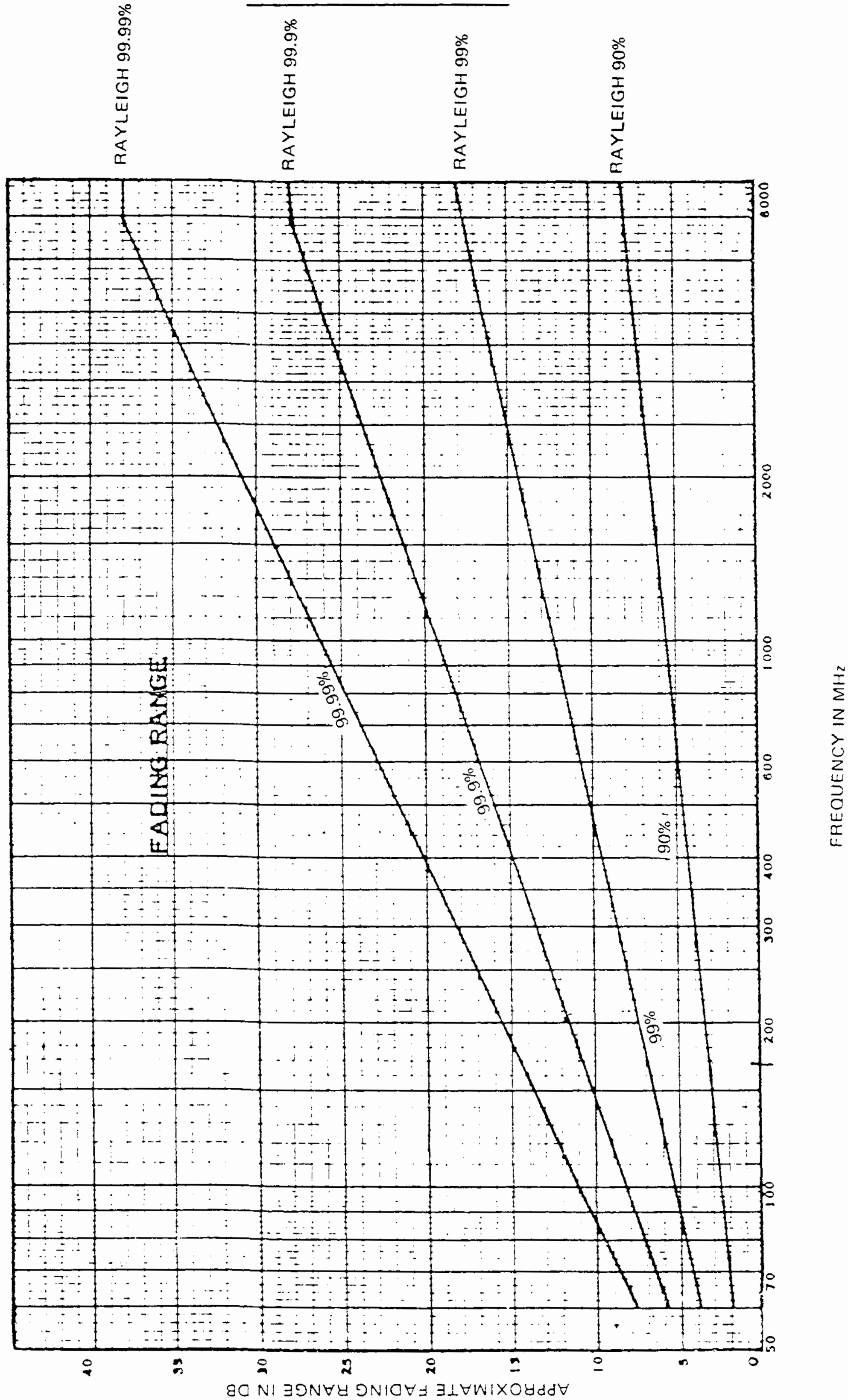
LOS path, except for immediate trees and/or buildings which are grazing the los path. The trees are assumed to block or absorb the ground-reflected ray.

System Losses

Free-space loss (figure 4-1)	110 dB
Shadow loss (figure 4-10)	0 dB
Transmission line loss (assuming 75-foot tower + lead-in (airborne [1])) (See figure 4-14)	2 dB
Hybrid loss (if allowed)	3 dB
Total Loss	115 dB

[1] Airborne feeder loss is considered to be negligible.

FIGURE 4-12. TYPICAL FADING IN WORST MONTH ON 30-TO-40 MILE LINE-OF-SIGHT PATHS



System Gains

Transmitter output (10 watts)	40 dBm
Antenna gains (both ends)	0 dBm
Effective radiated power	40 dBm

Received carrier level = -115 + 40 = -75 dBm

Fade margin = - 87 - (-75) = -12 dBm

b. Figure 4-12 indicates that a system reliability greater than 99.99 percent can be expected. To allow for errors in calculations and system parameter assumptions, and for general deterioration, it is recommended that an additional margin of 6 dB be allowed over and above the fade margin requirement indicated in figure 4-12.

38.-39. RESERVED.

SECTION 2. ANTENNAS

40. GROUND-BASED ANTENNAS.

a. Currently used vhf/uhf antennas are often simple structures such as dipoles or monopoles that do not have much directivity. Several requirements are imposed on vhf/uhf ground antennas used in communications with aircraft. Such antennas are usually required to have omnidirectional patterns in the horizontal (azimuth) plane. Ideally, their patterns in the vertical plane should be tapered to produce a uniform field for an aircraft flying a radial course either directly toward or directly away from the ground station, at constant altitude. Unfortunately, the ground produces lobes in the pattern which can result in signal dropouts over a particular path, depending on the heights of the two antennas, the distance between the antennas, the terrain characteristics at the ground reflection point, and the transmit frequency. These factors must be evaluated to assure that the nulls created in the antenna pattern will not penetrate the service volume and that continuous (or gapless) communications coverage will be achieved.

b. The antennas should exhibit broadband capabilities (low voltage standing-wave ratio (vswr)) over the FAA-specified frequency bands. Siting should preferably be in areas relatively void of large metallic bodies or lines that would produce undesirable perturbations in the horizontal pattern due to reflection and scattering. Specific siting practices for ground antennas include:

(1) Unobstructed propagation paths down to an elevation angle of 2 degrees above the horizon, including future vegetation growth.

(2) LOS paths to all taxiways, ramps, and runways.

(3) Minimum spacing of 8 feet between transmit or receive antennas.

(4) Minimum spacing of 80 feet between transmit and receive antennas if adjacent collocated frequencies differ by 1 MHz or less.

(5) Where the 8 or 80 feet separation cannot be met, the associated antennas shall be as far apart as possible.

41. ANTENNA CONFIGURATIONS.

a. At low-activity control towers, both transmit and receive antennas may be mounted on the roof of the cab, although the preferred practice is to separate them by mounting either the transmit or receive antennas on the cab roof and the other (receive or transmit) on towers located a fixed distance (80 feet minimum) from the control tower. Antennas located at remote sites (remote transmitter, remote receiver, RTR, and RCAG) are mounted on steel towers having hexagonal platforms. The antenna heights above ground should be determined on the basis of providing gapless coverage as presented in Order 6630.3 , Antenna Configuration Handbook for Terminal and En Route Facilities, Appendix 2.

b. To reduce the number of antennas required at a facility and also to avoid possible interference problems, several alternatives are available. One is the application of antenna couplers (multicouplers and hybrids), while another is the use of stacked antennas. More details on multicouplers are presented in paragraph 68. The stacked antenna is a new concept in ground-based antennas applicable to air traffic control communications in the vhf and uhf bands. Stacked antenna assemblies incorporate one or more vhf or uhf dipole antennas arranged in a collinear manner. Available units include vhf, uhf, vhf/vhf, vhf/uhf, and uhf/uhf. Each dipole within the multiple-unit structure is operated independently with a high degree of isolation. This eliminates or minimizes the need to horizontally dispense several antennas in a given installation. Thus, the penalty of large structures, high interaction, and mutual disturbance of radiation characteristics is eliminated. All dipole elements operate without retuning over the entire vhf (118 to 136 MHz) or uhf (225 to 400 MHz) bands.

c. Antenna parameters such as frequency, polarization, and type of radiation pattern determine the selection of antennas to be used for a particular application. General purpose antennas used for a-g communications at remote installations (remote transmitter, remote receiver, RTR, RCAG) include the circularly polarized swastika, the coaxial dipole, and discone types. Although swastika, coaxial dipoles, and discone types continue to be used, the new collinear family of antennas is preferred. The new standard antennas (TACO type) have proven to provide better communication coverage and operate under more severe weather conditions. Antennas providing increased gain may be required to provide additional coverage in some instances.

d. The FAA antennas currently in use include discones, swastikas, and coaxials, as well as the new standard antennas being procured. The new standard antennas currently being procured are described in paragraph 42. Additional information, including physical and electrical characteristics, is provided in Order 6630.3 , Antenna Configuration Handbook for Terminal and En Route Facilities, Appendix 1. The antennas described are manufactured by TACO, Sherburne, New York. The equivalent of each antenna type is currently also being procured from DHV, Mineral Wells, Texas.

42. NEW STANDARD ANTENNA TYPES. The following paragraphs describe the antennas presently being procured from TACO, Sherburne, New York, and DHV Incorporated, Mineral Wells, Texas.

a. TACO D-2276 and DHV DPV-35 Antennas. This type of antenna consists of a single vhf element operating in the frequency band of 118-136 MHz. The element is fed through the center of the lower half of the dipole. Currents are choked off the coaxial cable and mounting pole by use of a quarter wave coaxial stub combined with ferrite choking on the outside of the coxial input cable. The result is a clean donut-shaped radiation pattern. The antenna provides a nominal 50-ohm termination impedance.

b. TACO D-2277 and-DHV DPV-37 Antennas. This type of antenna consists of a single uhf element operating in the frequency band of 225-400 MHz. For operational details, refer to paragraph 42a.

c. TACO D-2272 and DHV DPV-36 Antennas. This type of antenna consists of two stacked vhf elements, operating independently in the frequency band of 118-136 MHz. The upper element is fed through the lower element. The upper element utilizes a quarter-wave coaxial choke combined with ferrite choking to avoid currents on the outside of the coaxial feed cable. This results in a clean donut-shaped radiation pattern. The lower dipole is isolated from the coaxial feed cable of the upper antenna by use of the same arrangement that is used to isolate the upper dipole from its own feed line. This arrangement is inverted and used to choke off currents on both coaxial input cables at the lower end of the lower dipole. With the current suppressed on the outside of all coaxial cables, clean donut-shaped radiation patterns are obtained for both elements. The suppression of these currents enhances isolation to at least 30 dB between the elements. Both elements provide a nominal 50-ohm termination impedance.

d. TACO D-2273 and DHV DPV-39 Antennas. This type of antenna consists of two stacked elements. One element is the vhf element and the other is uhf element, covering the frequency band of 118-136 MHz and 225-400 MHz, respectively. For operational details, refer to paragraph 42c.

e. TACO D-2274 and DHV DPV-38 Antennas. This type of antenna consists of two uhf stacked elements, each covering the frequency band of 225-400 MHz. For operational details, refer to paragraph 42c.

f. TACO D-2261A-1 and DHV DPV-40 Antennas. This type of omnigain antenna consists of vhf element(s) arranged to provide approximately 4 dBi gain in the frequency band of 118-136 MHz. The antenna provides a nominal 50-ohm termination impedance and exhibits a clean, donut-shaped radiation pattern.

g. TACO Y102B-130V and DHV YC118 Antennas. This type of vhf Yagi antenna operates in the frequency band of 118-136 MHz. It consists of a driven element(s), directors, and reflectors which provide a unidirectional gain of at least 10 dBi. The mounting arrangement is similar to that used for the omnidirectional antennas described above.

43. ISOLATION BETWEEN ANTENNAS. In practice, antenna radiation patterns differ from reference patterns (free-space) measured on the antenna range. When antennas are mounted on antenna towers, the radiation characteristics of the antennas are affected by the close proximity of other antennas and by the metal towers themselves. At any site, isolation between antennas is an important consideration in rf interference problems because most interference effects may be reduced by increasing the isolation. The relationships between vertical and horizontal separation versus isolation between antennas are shown in figures 4-13 and 4-14, respectively.

44. EFFECTS OF ANTENNA POLARIZATION. The efficiency of transmission between transmit and receive antennas is influenced by their polarization. Maximum rf signal transfer is obtained when the transmit and receive antennas have the same polarization. Conversely, a minimum signal is transferred between dissimilarly polarized antennas (vertical and horizontal or clockwise and counterclockwise). Utilizing two dissimilarly polarized antennas, the FAA's Technical Center found that up to 50 dB decoupling was obtained when the antennas were stacked vertically

with a separation of 10 feet. When lateral separation is a constraint, isolation between antennas can be increased in this manner. As was previously written, stacking is a desirable feature of the new multidipole antennas. Isolation between upper and lower antennas within a stack is at least 30 dB.

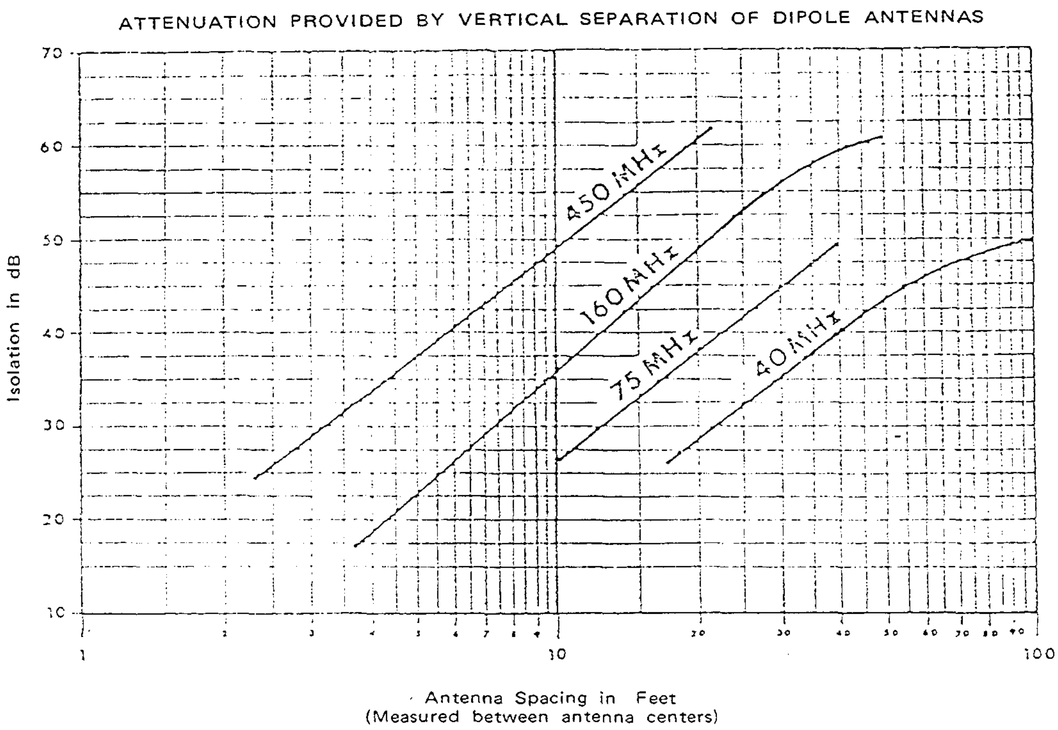
45. INCLEMENT WEATHER EFFECTS ON ANTENNAS.

a. At field sites, ice poses the most serious problem for antennas. The accumulation of ice on the antenna elements or insulators can increase antenna vswr sufficiently to impair the radiation efficiency. Antennas incorporating heaters have been used in areas where large accumulations of snow and ice damaged antennas or caused temporary outages in communication coverage.

b. Practices and procedures to provide effective lightning protection are described in the latest edition of Order 6950.19, Practices and Procedures for Lighting Protection, Grounding, Bonding, and Shielding Implementation. Antennas currently being procured that do not provide a dc short at the antenna connector are equipped with a grounding point to permit connection of an external AWG no. 6 wire for purposes of lightning protection.

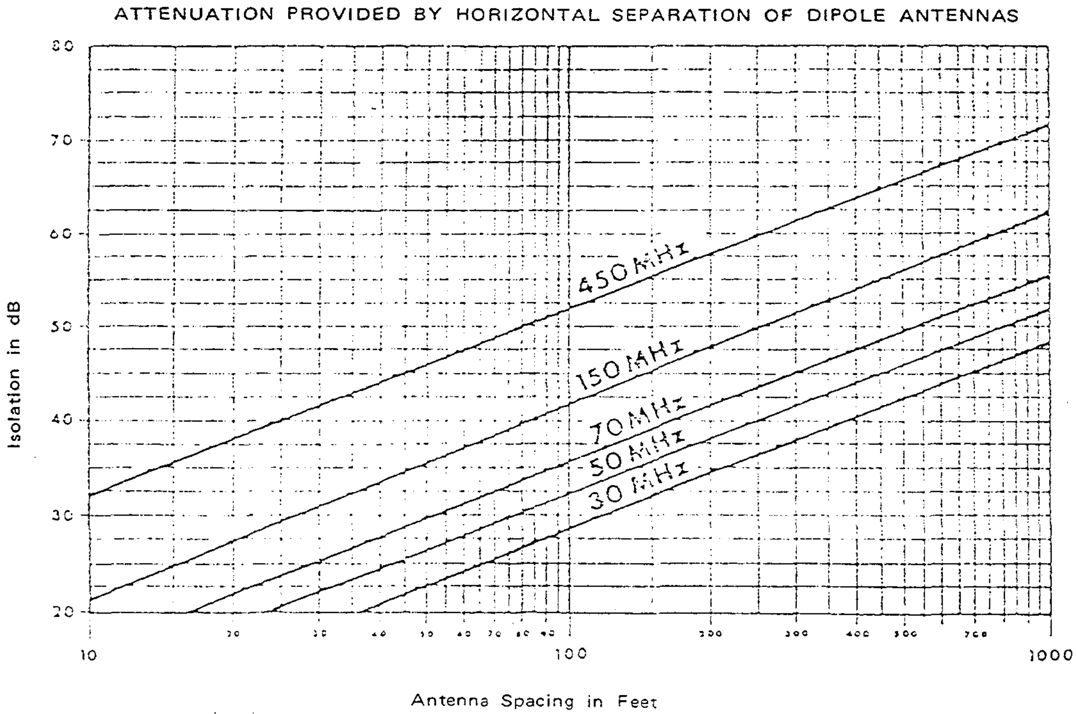
46.-47. RESERVED.

FIGURE 4-13. ATTENUATION PROVIDED BY VERTICAL SEPARATION OF DIPOLE ANTENNAS



NOTE: The values indicated by these curves are approximate values because of coupling which exists between the antenna and tower transmission line. Curves are based on the use of halfwave dipole antennas. The curves also provide acceptable results for gain type antennas if (a) the spacing is measured between the physical centers of the antennas and (b) one antenna is mounted directly above the other with no horizontal offset (exactly collinear). No correction factor is required for the antenna gains.

FIGURE 4-14. ATTENUATION PROVIDED BY HORIZONTAL SEPARATION OF DIPOLE ANTENNAS



NOTE: Curves are based on the use of halfwave dipole antennas. The curves provide acceptable results for gain type antennas if (a) the indicated isolation is reduced by the sum of the antenna gains and (b) the spacing between the gain antennas is at least 50 feet (approximately the far field).

SECTION 3. TRANSMISSION LINES

48. GENERAL.

a. The transmission line is the prime auxiliary to an antenna since it is the means for connecting a transmitter or receiver to an antenna. Coaxial lines, unbalanced to ground, are presently used in FAA antenna systems. One conductor is concentrically contained within the other, separated by a dielectric and covered with a vinyl resin jacket. The inner conductor is often of stranded untinned copper, while the dielectric insulating material is generally Teflon or polyethlyene. The outer conductor is a braided copper sheath or shield which is normally connected to ground through the associated connector and is an integral part of the circuit.

b. Type RG-214/U cable is generally used between the antenna and coaxial junction box atop the antenna tower at remote sites, and also for interrack cabling. Type RC-218/U is used for long, continuous cable runs between the antenna junction box and the antenna patch panel in the equipment building.

49. CABLE DEFICIENCIES. Connector pin pull-out could result from the use of some types of coaxial cables at sites subject to extreme temperature changes, causing deformation of the solid dielectric. Another deficiency associated with cables in which a single-braid shield is used is relatively more rf leakage than that associated with double-shielded cables. To overcome these deficiencies and reduce transmission loss, the use of foam dielectric cable with double shielding is recommended.

50. TRANSMISSION LINE LOSS.

a. Loss in a coaxial cable transmission line is a function of the physical construction of the cable and the rf frequency at which it is used. Typical losses for various cable types are shown in figure 4-15.

FIGURE 4-15. TYPICAL TRANSMISSION LINE LOSS FOR 120-FOOT LENGTHS OF CABLE

Frequency	Cable Type	Line Loss in dB
118.2 MHz	RG 213/U	2.61 dB
	RG 218/U	1.38 dB
	RG 331/U	1.05 dB
	RG 333/U	0.68 dB
300 MHz	RG 213/U	4.16 dB
	RG 218/U	2.48 dB
	RG 331/U	1.76 dB
	RG 333/U	1.15 dB

Line losses can be estimated by considering that attenuation varies approximately as the square root of the frequency ratio and is directly proportional to the length of line. The formula to estimate loss is:

$$L_E = L_C \sqrt{\frac{F1}{F2}}$$

where L_E is the estimated loss in dB per 100 feet; L_C is the known loss in dB per 100 feet; F1 is the frequency at which the loss is to be determined; and F2 is the frequency at which the known loss occurs. For RG-213U, the attenuation of 100 feet of cable at 100 MHz is 2.2 dB. Therefore, the attenuation at 125 MHz is:

$$2.2 \text{ dB} \sqrt{\frac{125}{100}} = 2.46 \text{ dB}$$

This formula becomes less accurate with increase in frequency.

b. The inherent transmission line losses of RG-213/U and RG-218/U necessarily limit the length of coaxial line required to connect an antenna to receive or transmit equipment. When the length of required cable is 100 feet or more, RG-331/U or RG-333/U should be used for the major portion of the line, whether at vhf or uhf. The FAA permits the use of RG-213/U (or equivalent) for the entire length of line only in those cases where RG-331/U or RG-333/U is not practical to use because of duct configuration or space limitations.

51. FOAM DIELECTRIC CABLE.

a. Foam dielectric cable consists of a high-conductivity copper inner conductor encircled by a cellular polyethylene dielectric foam and an outer conductor consisting of a high-strength solid aluminum sheath. This cable will eliminate the deficiencies mentioned earlier and should be used for all future installations if its increased cost can be justified.

b. Transmission losses for 100-foot lengths of RG-213/U, RG-218/U, and foam (RG-331/U, RG-333/U) are indicated in figure 4-14. A plot of manufacturer's data for cable attenuation versus frequency is given in figure 4-15 for the above-mentioned cables, and related attenuation correction factors for temperature are provided for foam cable in figure 4-16.

52. RESERVED.

FIGURE 4-16. TYPICAL TRANSMISSION LINE LOSS FOR 100-FOOT LENGTHS OF CABLE

Test Frequency (MHz)	Cable Type	Line Loss (dB)
118.2	RG-213/U	2.4
118.2	Foam	0.88/0.57 1/
118.2	RG-218/U	1.05
134.9	RG-213/U	2.6
134.9	Foam	0.91/0.61 1/
134.9	RG-218/U	1.15
150.2	RG-213/U	2.7
150.2	Foam	1.00/0.65 1/
150.2	RG-218/U	1.23
225.0	RG-213/U	3.45
225.0	Foam	1.25/0.79 1/
225.0	RG-218/U	1.63
300.0	RG-213/U	4.1
300.0	Foam	1.47/0.96 1/
300.0	RG-218/U	1.95
399.9	RG-213/U	4.9
399.9	Foam	1.7/1.06 1/
399.9	RG-218/U	2.4

1/ First figure represents attenuation for RG-331/U; second figure figure for RG-333/U

FIGURE 4-17. TYPICAL CABLE ATTENUATION CHARACTERISTICS

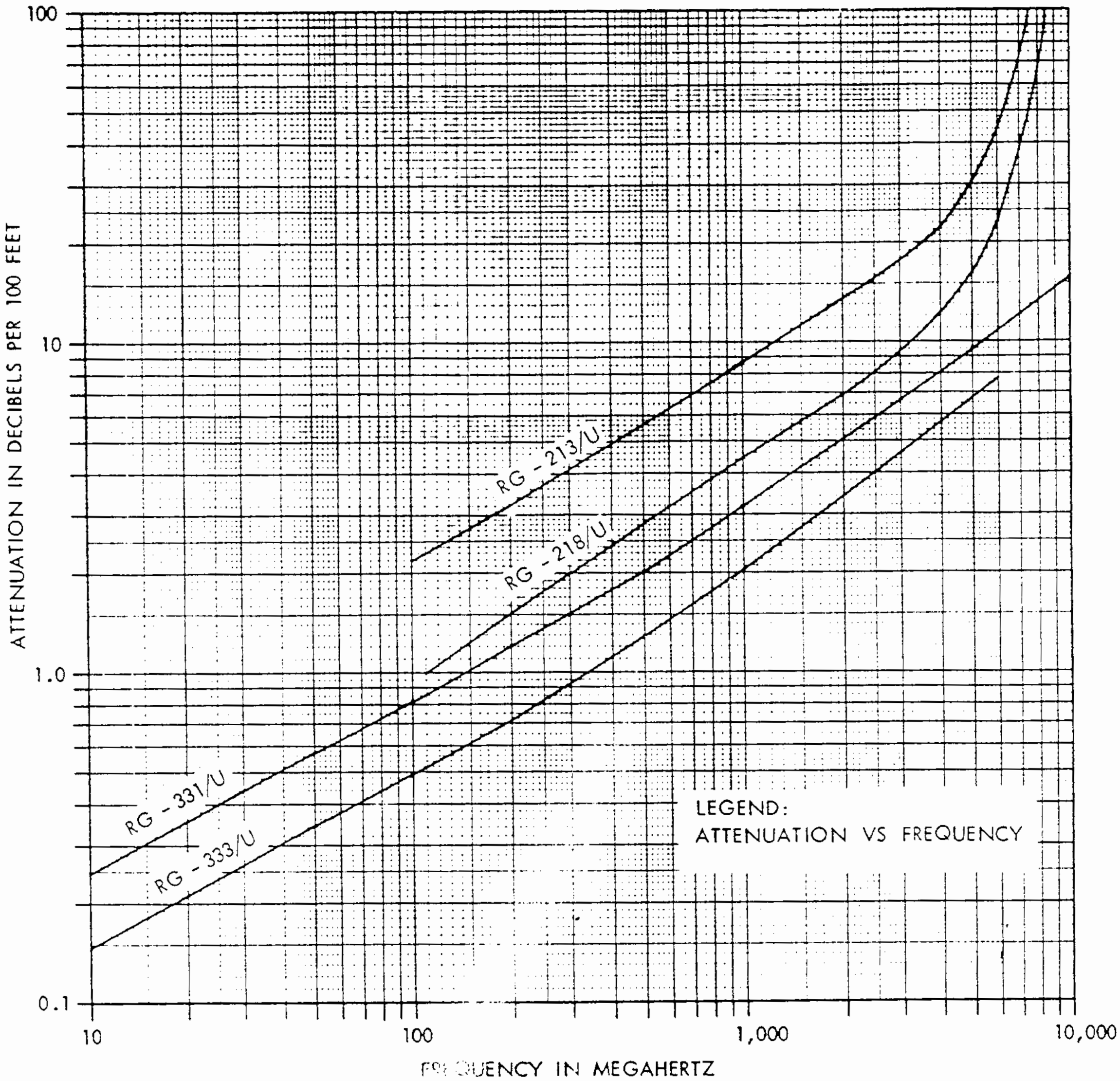
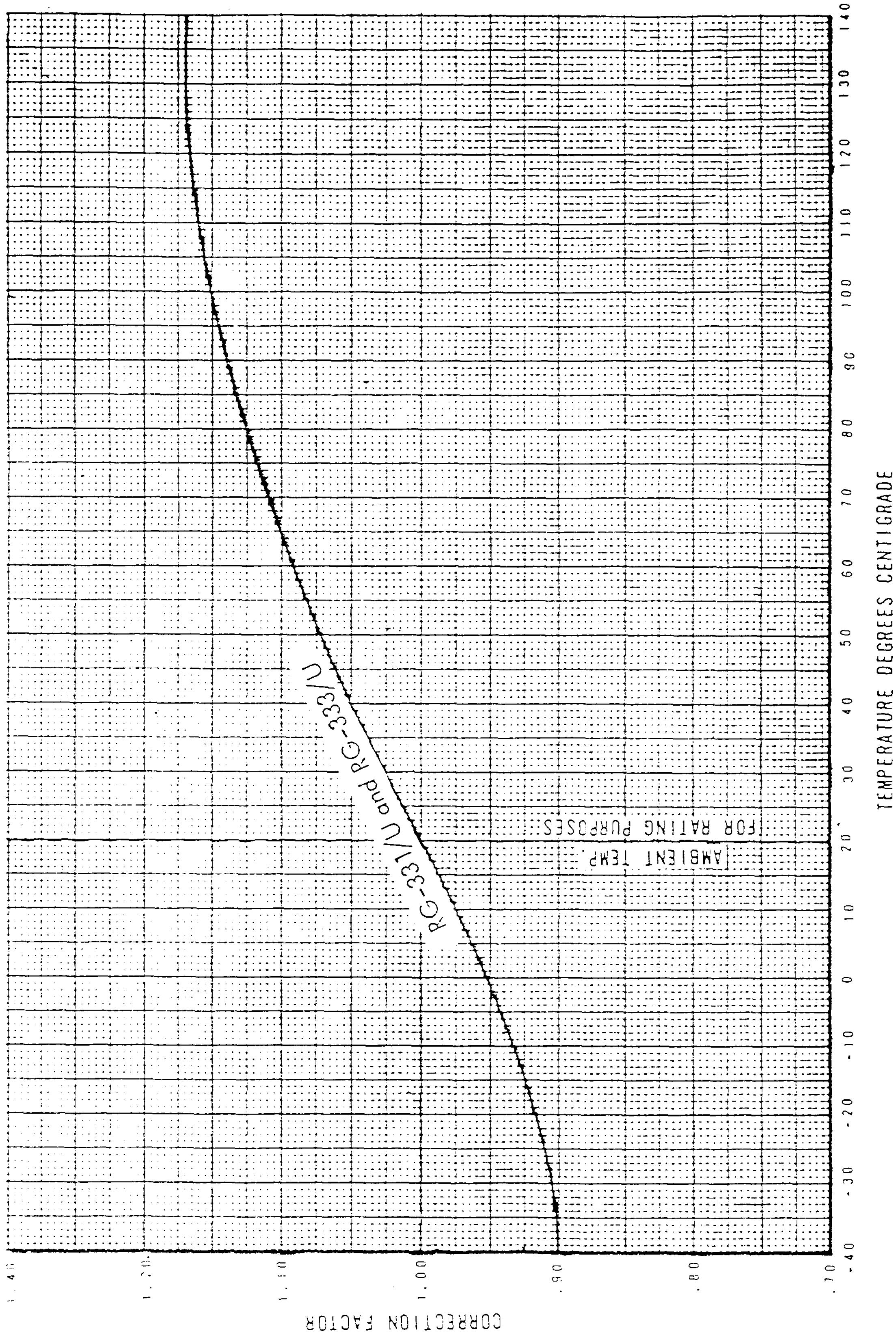


FIGURE 4-18. TYPICAL FOAM CABLE ATTENUATION CORRECTION FACTOR FOR TEMPERATURE



SECTION 4. INTERFERENCE AND NOISE

53. GENERAL.

a. The intelligibility of a received signal is limited by noise, which, in the broadest sense, is any type of interference. Interference can be regarded as noise resulting from natural or man-made static disturbances (either discontinuous or continuous). Discontinuous disturbances may occur rather infrequently as impulse noise or quite frequently as random noise.

b. The noise that is of major concern for this order is referred to as radio-frequency interference. It includes those continuous disturbances resulting from signal harmonics radiating on the same or adjacent channels and harmonics of other transmitters or oscillators. The main sources of interference of most concern to the FAA are transmitter noise, transmitter spurious radiations, transmitter intermodulation, receiver desensitization, receiver selectivity, receiver spurious responses, and receiver intermodulation.

c. Each type of interference created by extra-band radiation from a transmitter results in a corresponding type of interference generated in the receiver. The degree of importance of transmitter extra-band radiation from the standpoint of interference potential is a direct function of receiver performance. In general, receiver performance is superior to transmitter performance for all types of interference except intermodulation. Each type of interference will be examined in the following paragraphs.

54. TRANSMITTER NOISE. When a transmitter is keyed, most of the output power of the transmitter is confined within a narrow band of frequencies on the assigned transmit channel. However, some of this power is also radiated on other frequencies above and below the carrier frequency. This undesired radiation is referred to as transmitter noise. Sufficient noise energy is radiated from transmitters to degrade the performance (desensitization) of a receiver operating several MHz and/or several thousand feet away. To the receiver, transmitter noise appears as on-channel noise interference and cannot be filtered out at the receiver. It falls exactly on the receiver operating frequency and competes with the desired signal because the receiver sensitivity is reduced. Transmitter noise interference can be reduced or minimized by means of bandpass cavity or notch filter devices installed at the transmitter.

55. TRANSMITTER SPURIOUS AND HARMONIC RADIATION.

a. Transmitter spurious and harmonic radiations are essentially narrow-band phenomena. Harmonics of the crystal oscillator frequency and of the transmitter output frequency are generated in the frequency multiplier circuits and in the nonlinear final stage of most transmitters and, unless attenuated, are radiated. Spurious (or parasitic) frequencies are often generated by some resonance created by stray inductances and/or capacitances somewhere in the transmitter. These frequencies are usually incoherent with the desired frequency.

b. Low pass filters in the transmission line and improved receiver selectivity performance (by means of a bandpass cavity) can minimize adverse effects from harmonic and spurious radiations from transmitters.

56. TRANSMITTER INTERMODULATION (IM). Transmitter im product interference occurs, at a communications facility, when two or more assigned frequencies produce im products on the desired frequency of one or more active receive channels. Management of frequency assignments normally avoids these frequency combinations whenever possible. However, there is a finite limit on the number of available channel frequencies for any specific communications service in any FAA region. Therefore, transmitter im product frequency combinations cannot always be avoided.

a. Intermodulation interference signals generated in the final amplifier of a transmitter usually involve one or more offending signals external to the transmitter traveling backward along the output cable from the transmit antenna, reaching the amplifier and combining there with each other or with the transmitter's signal. The resultant interference signal then travels back on the output cable to the antenna to be radiated. In general, the output amplifier is the nonlinear component in which most transmitter im products are generated. However, any nonlinear device can be a mixing agent for im products. These include such things as loose or corroded joints between two conductors, obstruction light filaments, lightning arrestor blocks on telephone lines, and even the front end of the receiver itself.

b. For two frequencies, f_1 and f_2, im products appear as the sums and differences of multiples of f_1 and f_2, namely, at:

$$nf_1 \pm mf_2$$

where n and m are positive integers. The order of the im product is the sum n + m, the coefficients of f_1 and f_2.

c. The level of im energy radiated by several transmitters depends upon their physical proximity, frequency separation of their carriers, absolute carrier levels, and the order of the intermodulation. Usually third-order products are most serious, followed by fifth-order products.

d. The amount of energy coupled between transmitter power amplifier circuits can be controlled by:

(1) Increasing the spatial separation between antennas.

(2) Using band reject and bandpass filters in the output transmission lines.

(3) Using isolation devices such as ferrites and hybrid networks.

57. RECEIVER DESENSITIZATION.

a. The presence of an interfering signal in the front end (rf stages) of a receiver tends to reduce the sensitivity of the receiver. The strength of the interfering signal necessary to produce this effect is dependent on the frequency spacing between it and the desired signal. Since the front end of the receiver is frequency selective, it can attenuate an incoming signal by greater amounts as the frequency spacing is increased. The degree of desensitization, therefore, increases as the frequency spacing is decreased and decreases to a point of no consequence if the frequency spacing is sufficiently increased. The effect of the interfering signal is to reduce the gain of the rf amplifier stage.

b. Receiver desensitization or blocking can be minimized or eliminated by means of filters installed at the receiver to sharpen the selectivity characteristic and thus make the receiver less responsive to off-frequency signals.

58. RECEIVER SELECTIVITY. Selectivity is the ability of a receiver to differentiate between a desired signal and signals at other frequencies. It is a measure of the bandpass characteristics of a receiver at 6 dB and skirt selectivity at 60 dB, the attenuation taken to indicate adequate discrimination against an interfering signal. It is desirable to have the bandwidth at 60 dB down as narrow as possible without making the 6 dB passband too narrow for satisfactory reception of a desired signal. The ratio of bandwidth at 60 dB down to that at 6 dB down is referred to as shape factor.

59. RECEIVER SPURIOUS RESPONSE.

a. The most common nonlinear device in which frequency mixing occurs is the front end of a receiver. If two or more signals on their respective frequencies enter a receiver, the signals can mix together in the circuitry of the receiver and produce undesired responses within the receiver. If one of these responses happens to fall on or near a frequency to which the receiver is tuned, this spurious signal will be audible and often intelligible.

b. The generation of spurious responses in receivers can be predicted from the equation:

$$F_{SR} = \frac{pf_{LO} \pm f_{IF}}{q}$$

where F_{SR} = spurious response frequency

q = harmonic number of the incoming signal involved

f_{LO} = local oscillator frequency

p = harmonic number of the local oscillator frequency involved

f_{IF} = intermediate frequency

Responses are generally strongest in a receiver when $p = q = 1$, which corresponds to the desired signal and its image frequency. Values p and q other than unity indicate mixing and harmonics resulting in responses which are generally lower in amplitude though more numerous. A bandpass filter tuned to the receiver frequency and installed between the receiver and antenna can improve receiver selectivity and prevent spurious responses.

60. RECEIVER IM.

a. Receiver im is the interference level which results when two signals combine in a receiver to produce a multitude of product signals due to nonlinear effects in the receiver which interfere with the desired frequency. The most common annoyance is the third-order im product which occurs when two undesired signals, f_1 and f_2, combine to produce interference on the desired frequency, f_0, in a manner such that $2f_1 - f_2 = f_0$. Higher orders than the third may cause interference in receivers but are less frequent. To reduce im interference in a receiver, nonlinearities in the preselector, amplifier, and/or mixer responses must be curtailed.

b. Filters can be used to reduce or eliminate im in a receiver where the level is high enough to cause objectionable interference.

61.-62. RESERVED.

SECTION 5. INTERFERENCE ELIMINATION

63. GENERAL.

a. Paragraph 53 discusses various types of interferences common to vhf/uhf a-g communications and notes possible ways to remedy the interference. The following paragraphs describe, in some detail, ancillary equipment that is available for minimizing or eliminating interference problems when inadequate space separations exist between transmit and receive antennas. The increase in electrical isolation that can be achieved with these devices provides, in effect, increased attenuation of undesired frequencies. There is, in addition, a discussion on equipment for reducing the number of antennas required at a transmit or receive site.

b. Although certain devices are described that are effective in eliminating/reducing interference problems and for minimizing antenna requirements, application of these devices for use in the National Airspace System will require a waiver from the Communications and Surveillance Division, APM-350, FAA Headquarters, Washington, D.C. The National Airspace System Plan calls for consolidation of communications sites in an effort to reduce costs. It is anticipated that certain devices will become standard equipment and the requirement for waivers will be rescinded.

64. COAXIAL CAVITY FILTER.

a. The bandpass cavity is a high Q resonant circuit designed to pass a narrow band of frequencies with very little loss while attenuating all other frequencies. As the frequencies are further removed from the resonant frequency of the cavity, they become more attenuated. The narrow band of frequencies that pass through with only slight loss is within a few kilohertz of the cavity's resonant frequency. Energy is fed into the cavity by means of a coupling loop which excites the resonant circuit formed by the inner and outer conductors. A second loop couples energy from the resonant circuit to the output. The selectivity response of the cavity will generally improve significantly as the coupling loops are changed to a higher insertion loss at the desired frequency (from 0.5 dB to 1 dB, etc.). Coupling loops that can be rotated to achieve different insertion loss settings are much more convenient than loops that must be replaced. If a single cavity will not provide sufficient attenuation to an undesired signal, additional cavities can be added in series to improve the selectivity characteristic. Note that a multicavity combination is more efficient than a single cavity. For example, a three-cavity combination with each loop set for 1 dB of insertion loss (3 dB total insertion loss) will have a greater selectivity than a single cavity with loops set at 3 dB.

b. A bandpass cavity tuned to the receive frequency and installed between the antenna and associated receiver will improve the receivers selectivity considerably. The cavity will reduce or minimize off-frequency signals that might otherwise pass into the receiver's front-end circuits to cause receiver desensitization, spurious responses, or im interference. A bandpass cavity tuned to a transmit frequency and installed between a transmitter and associated antenna will reduce spurious and harmonic radiations and/or transmitter sideband noise that might otherwise be radiated from the transmitter and degrade the performance of a nearby receiver. The use of bandpass cavities in the transmitter circuit may also reduce or minimize transmitter im interference since all off-frequency signals from other nearby transmitters will be attenuated as they try to pass through the cavity to the transmitter's final circuits. Where frequency separations are inadequate, coaxial cavities can increase isolation between transmit and/or receive antennas.

65. BAND-REJECT FILTERS.

a. The band-reject cavity filter, or notch filter, is a high Q resonant circuit that attenuates a narrow band of frequencies while allowing all other frequencies to pass through with only slight loss. Basically, it is the opposite of a band pass cavity. Maximum attenuation occurs at the resonant frequency of the filter while all other frequencies are attenuated to a lesser degree, depending on their distance from the resonant frequency. The notch filter provides a given amount of attenuation at resonance regardless of the separation between the pass and reject frequencies. The filter can be tuned so that the narrow band of rejected frequencies can be several magahertz from the desired pass frequency or quite close. Notch filters can be added in series to obtain additional attenuation to an undesired frequency.

b. Notch filters, as in the case of the bandpass cavity, can be used with transmitters to reduce or minimize transmitter noise radiation and transmitter im interference. They can be used with receivers to reduce or prevent receiver desensitization and to reduce or prevent receiver im interference. However, remember that a notch filter provides maximum attenuation only at a specific, relatively narrow band of frequencies. The single most important feature of a notch filter is its ability to reject an undesired frequency extremely close to the desired frequency.

66. BANDPASS CAVITY FILTER VERSUS NOTCH FILTER. The choice between a bandpass cavity filter and a notch filter to solve a particular interference problem is dependent on several system factors. In general, the following guidelines apply:

a. A bandpass cavity filter is the best choice for solving an interference problem if the nature of the interference and/or frequencies of the interfering signals is not known.

b. A notch filter will generally provide greater attenuation to an undesired frequency than a bandpass cavity filter of comparable size when the separation between desired and undesired frequencies is less than 1 MHz on vhf and 3 MHz on uhf.

c. A bandpass cavity filter generally provides greater attenuation to an undesired frequency than a notch filter of comparable size when the separation between desired and undesired frequencies is greater than the values mentioned in item b.

d. A notch filter can be field-converted into a bandpass cavity, or vice versa, by a modification kit. More details can be obtained from the manufacturer.

67. CRYSTAL FILTERS. These filters are used as front-end filters for vhf communication a-g receivers. The physical configurations are designed to accommodate in-line installation between the antennas and receivers. A typical design incorporates a four-pole monolithic integrated crystal filter with a 3 dB bandwidth of

19 kHz and a 50 dB bandwidth of 80 kHz. Insertion loss may be as high as 6 dB but normally is around 4.5 dB. While filters of this type are very effective interference eliminators, their inherent insertion loss may cause missed calls. Therefore, their use may compromise service to some extent.

68. MULTICOUPLER.

a. The basic function of a receiver multicoupler is to reduce the number of antennas at a site by distributing the appropriate receive frequencies from a single antenna to their respective receivers with minimum loss and very low im signal generation. An active mulicoupler consists of a preamplifier followed by a distribution and isolation network which allows signals to pass from the antenna to any receive ports, but attenuates energy passing between any pair of receive ports in order to reduce front-end receiver intermodulation from affecting adjacent channels. In general, multicouplers have excellent isolation (40 dB minimum) which prevents variations in load impedance and keeps local oscillator radiation from coupling into the outputs. Intermodulation distortion is negligible, as is insertion loss. In addition to increasing the isolation between receivers, a multicoupler allows a receiver to be removed from service without interrupting service to the other receivers. With FAA's present-day practice of utilizing a single antenna with multiple receivers, removal of a receiver from service could interrupt the operation of the other receivers.

b. While there is not currently a national standard for receive multicouplers, recent increases in their application is expected to lead to standardization and procurement by national contract. Multicoupler use is now, by waiver approval, in accordance with the latest edition of Order 6000.20, Waiver of Criteria for Establishment and Maintenance of Airway Facilities. Receive multicouplers used in FAA systems should provide the following minimum characteristics:

Frequency range:	118-136 MHz [1/] 225-400 MHz [1/]
Input/output impedance:	50 ohms, nominal
Input/output vswr:	1.6:1 maximum (with all parts terminated)
Number of output ports:	8 minimum
Port-to-port isolation:	40 dB minimum
Gain:	2 dB ± 2 dB
Noise figure:	8 dB maximum
Spurious radiations:	80 dB below input signal level
3rd order im level:	60 dBm down minimum

[1/] To include front-end filter.

RF input level:	+ 10 dBm or better
RF input/output connectors:	Type N female
Power input:	115 V ac ± 10 V ac, 26 V dc ± 4 V dc
Service life:	25,000 hours MTBF
Environmental operating temperature	-10° C to 50° C

69.-70. RESERVED.

CHAPTER 5. REMOTE FACILITIES

71. GENERAL.

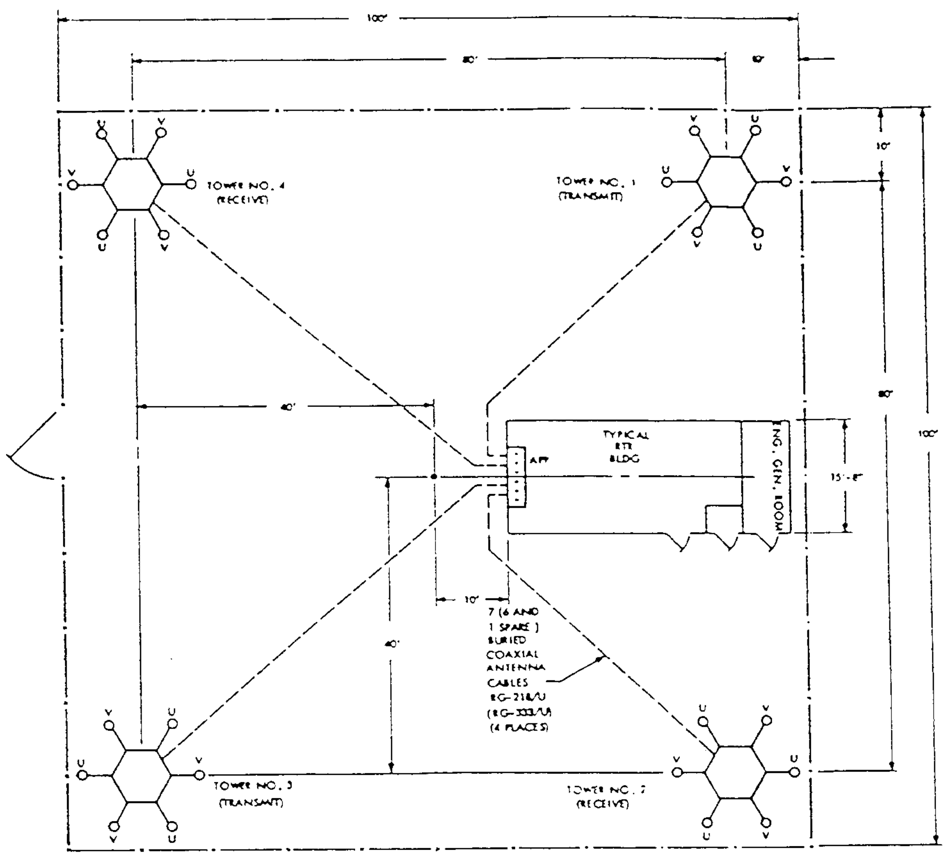
a. Remote facilities are used in terminal and en route communications to improve communication coverage, to reduce mutual interference between transmitters and receivers, and to improve the appearance of control tower buildings by eliminating or reducing the large number of antennas on the roof of the tower cab.

b. Requirements for remote facilities are defined by the latest edition of FAA Order 6510.4, Radio Communications Requirements for Air Traffic Control Facilities. Over the past several years, the combined RTR site has become the preferred type of remote facility. Figure 5-1 depicts a typical remote site layout applicable to remote transmitter, remote receiver, and RTR sites; and in the case of en route communications, applicable to an RCAG site. All sites include an equipment building and appropriately spaced (80 feet minimum) steel antenna towers with hexagonal platforms. If figure 5-1 represents a remote transmitter site, the equipment building would house the necessary vhf and uhf radio transmitters, and appropriate vhf and uhf antennas would be alternated on the towers as indicated. In the case of a remote receiver site, the building would house radio receivers, and receive antennas would be mounted on the towers. For RTR and RCAG applications, both transmit and receive equipment would be collocated in the building, and separate towers would be dedicated to transmit and receive antennas. Typically, towers 1 and 3 would be for transmit antennas and 2 and 4 for receive antennas. With this layout, the 80-foot separation between adjacent transmit and receive antennas should preclude effects of receiver desensitization while a maximum diagonal separation of 113 feet between transmit antennas should tend to reduce transmitter intermodulation interference.

c. Remote sites are unattended and located at points in a control area to provide areawide coverage. Remote transmitter, remote receiver, and RTR sites are usually located in airport property and linked to the controlling ATCT by means of FAA-owned vf cables. An RCAG is almost always located beyond FAA property boundaries and, therefore, is interconnected to the controlling ARTCC by a leased voice-grade circuit owned and maintained by various telephone and telegraph companies.

d. There is a significant increase in communication channel requirements. In order to minimize interference and allow more efficient use of the available frequency spectrum, a power reduction program was instituted in April 1975 (Order 6610.3, Power Output Limitation: FSS, Terminal and Low-Altitude En Route VHF and UHF Transmitters) for vhf and uhf transmitters installed in FSS, terminals, and low-altitude en route facilities. Ten-watt power outputs are to be used for all applications except where: (a) required coverage cannot be attained, (b) when serving a high-altitude sector, or (c) where the radius of service volume exceeds 60 nautical miles. Waiver approvals are required for higher outputs, unless serving high-altitude sector or service volumes exceeding 60 nautical miles. Fifty-watt amplifiers are in the FAA depot stock to support coverage as required. Although high-altitude en route facilities are not affected by the power reduction program, 50-watt outputs are permissible, and indeed expected by the Air Traffic Service. However, where sectors are small and satisfactory coverage can be provided, there is no objection to the use of 10-watt power. As in the past, it is

FIGURE 5-1. TYPICAL RTR/RCAG SITE LAYOUT



incumbent upon the Air Traffic Service to coordinate anticipated changes in sector boundaries with Program Engineering and Maintenance Service. The importance of this coordination is magnified where 10-watt power is currently used, and 50 watts dictated by new boundaries.

72. REMOTE TRANSMITTER SITE. When an airport complex requires a single remote facility, it is normally designated the transmitter site. At nonradar facilities not qualifying for loop cables (reference the latest edition of Order 6510.4, Radio Communications Requirements for Air Traffic Control Facilities), main transmitters will be located at the transmitter site, and some standby transmitters (on non-interfering frequencies) will be located in the control tower equipment room. This technique will improve circuit reliability since cutting of the vf interconnect cable would not render all transmitters unusable.

73. REMOTE RECEIVER SITE.

a. A remote receiver site is not suggested unless it is necessary to provide adequate coverage or to eliminate noise and/or interference. Two arguments support this rationale: (1) the cost involved in providing a remote site, and (2) the fact that the control tower is usually the highest structure on the airport, thus providing the best antenna coverage. At nonapproach control towers, a preferred antenna arrangement is to locate transmit or receive antennas on the cab roof and to mount the other antennas (receive or transmit) on towers located 80 feet from the control tower. This configuration provides the desired interference-free operating characteristics and eliminates the need for a costly remote receiver site. Of course, at higher activity level control towers, a remote receiver site may be required to eliminate interference and provide better area coverage; but in this case, the number of equipments, level of activity, and probability of poor communications may justify the cost of a remote site.

b. As with the transmitter site, a remote receiver site, without loop cables, should not contain all main and standby receivers. Main receivers should be installed at the remote site, and some standby receivers should be installed in the control tower equipment room.

74. RTR SITE. The RTR site is the preferred facility relative to separate remote transmitter and remote receiver sites. One advantage of an RTR site is that the transmit and receive path to an aircraft is the same, thereby eliminating the possibility of multipath effects. Multipath effects are produced by the simultaneous reception of the direct wave, earth-reflected wave, ground wave (generally unimportant at frequencies above approximately 100 MHz) and the atmospheric wave (ionospheric and tropospheric), or any combination of these waves. For detailed information on multipath effects, refer to Ultra High Frequency Propagation by Henry R. Reed and Carl M. Russell. Another advantage, of course, is that the RTR site cost is half of the cost of separate remote transmitter and remote receiver sites. Three RTR sites provide greater flexibility in reducing im product interference effects than can be obtained from two remote transmitter and one remote receiver site. This is accomplished by distributing the im product generating frequency combinations over the three RTR sites rather than the two remote transmitter sites.

75. RCAG SITE. The RCAG site, the primary communications outlet for an ARTCC, is an unattended facility that may be located several hundred miles from the controlling ARTCC. VF signaling equipment connects the ARTCC to the RCAG to provide peripheral vhf/uhf a-g communications. The RCAG site is almost identical to the RTR facility, except that main and standby receivers in an RTR may be connected in multiple to a common antenna, while receivers in an RCAG are typically connected to antennas via a coaxial switching relay.

76. RESERVED.

APPENDIX 1. REFERENCES

In addition to equipment manuals, the following documents are referenced in this order. In each case, the latest issue in effect at the time of issuance shall take precedence over the contents of this order.

1. FAA Orders.

6000.15	General Maintenance Handbook of Airway Facilities
6000.20	Waiver of Criteria for Establishment and Maintenance of Airway Facilities
6030.20	Provisions of Electrical Power for National Airspace System Facilities
6480.4	Airport Traffic Control Tower Siting Criteria
6510.4	Radio Communications Requirements for Air Traffic Control Facilities
6630.3	Antenna Configuration Handbook for Terminal and En Route Facilities
6630.4	En Route Communication Installation Standards Handbook
6630.5	Terminal Communications Installation Standards Handbook
6610.3	Power Output Limitation: FSS, Terminal and Low Altitude En Route VHF and UHF Transmitters.
6630.2	Maintenance of Communication Transmission Lines
6930.26	Antenna Support Arms Modification
6950.2	Power Policy Implementation at National Airspace System Facilities
6950.19	Practices and Procedures for Lightning Protection, Grounding, Bonding, and Shielding Implementation
6960.1	Sanitary Systems in FAA Facilities

2. FAA Reports.

NA-68-1 (RD-67-60)	Test and Evaluation of VHF/UHF Antennas, Nov. 1968
RD-71-76	VHF/UHF Ground-Air-Ground, Nov. 1968 Communications Siting Criteria, Nov. 1971

3. Drawings

Series D-6061 D-6068, D-6069, and proposed series D-6188	Site Layouts

4. Other Documents.

Ultra High Frequency Propagation, H.R. Reed and C.M. Russell

Antenna Engineering Handbook, McGraw-Hill Book Company, N.Y., 1961

Radio Propagation Above 30 Megacycles, Proceeding of the IRE, October 1947

Ultra High Frequency Propagation, Science Paperbacks and Chapman & Hall Ltd.